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A comparison of hip and knee torques produced during a maximal effort full and partial back squat

Jordan Alexander Williams
University of Northern Iowa

A COMPARISON OF HIP AND KNEE TORQUES PRODUCED DURING A MAXIMAL EFFORT FULL AND PARTIAL BACK SQUAT

An Abstract of a Thesis

Submitted

in partial fulfillment

of the requirements for the Degree

Master of Arts

Jordan Alexander Williams

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ABSTRACT

This study examined the levels of hip and knee torques produced during a one repetition maximum (1RM partial) squat and full squat in order to determine if there would be a difference in the peak torque created at the two depths.

Eight male athletes (standing height = 1.84 ± 0.07 m; mass = 87 ± 14 kg; age 23 ± 2.1 years) volunteered for the study. Each subject performed a 1RM squat at full squat (as low as the participant could go, at least 0° or thigh parallel in relation to the ground) and partial squat (thigh at 45° in relation to the ground). The trials were collected in two sessions one week apart. The joint torques were calculated at the instant they reached the maximum depth for each trial, as well as at 45° in the full squat trials.

The difference in knee and hip extension torques achieved was not significant at maximum depth ($p \geq .05$). The full squat achieved the same level of hip and knee torque as the partial squat with significantly less barbell load. Participants averaged a 60.5% increase in barbell load, which was significant ($p < .05$), in the partial squat when compared to the full squat.

Due to the large increase in barbell load during the partial squat, the participants mentioned much more discomfort and were less inclined to approach a true 1RM as they did with the full squat. The partial squat also slightly changed the mechanics of the squat with the subjects maintaining a more erect posture to alleviate some of the strain placed on the spine and back musculature which could place the spine at an increased risk for injury. For the partial squat to be an effective training lift, the participants would have to

increase the load to a point that they find uncomfortable and place the spine under excess stress than would a full squat that would achieve the same levels of joint torques.

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APROVAL PAGE

This Study by: Jordan Alexander Williams

Entitled: A Comparison of Hip and Knee Torques Produced During a Maximal Effort Full and Partial Back Squat

has been approved as meeting the thesis requirement for the

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Date	Dr. Travis Ficklin, Chair, Thesis Committee
Date	Dr. Robin Lund, Thesis Committee Member
Date	Dr. Forrest Dolgener, Thesis Committee Member
Date	Dr. April Chatham-Carpenter, Interim Dean, Graduate College

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CHAPTER I

INTRODUCTION

The back squat is a strength and conditioning lift that is a cornerstone movement of most strength programs. It is a dynamic strength exercise that is popular in programs for sports that require a high level of strength and power such as football, track and field, powerlifting and Olympic weightlifting. The squat strengthens the hip, thigh, and back musculature which are used in a variety of dynamic movements. The squat has also been shown to minimize the risk of injury in movements that involve those muscle groups and joints (Escamilla, 2001).

The knee is a particularly vulnerable joint in athletics. Most coaches are apprehensive about involving any activity that puts this joint at an increased perceived risk. On the other hand, they see the importance of the barbell back squat to develop peak strength in the legs. This has led to variations of the back squat and one common variation is the depth of the squat (Hartmann, Wirth, & Klusemann, 2013). The most common variations of squat depths used are the deep squat, where the hamstrings rest against the calves with the athlete not being able to flex the knees any more while maintaining an erect spine. Another variation is the parallel squat. It is most commonly measured by the top of the thigh being parallel to the floor. It may be of importance to note that although the two former depths differ slightly, they have both been referred to in the literature as a full squat (Hartman et al., 2013). Finally, the partial squat measured as having a thigh angle in relation to the ground above 0°, or parallel, and below 45°. The partial squat variation is thought to place less tension (torque) on the knee and hip joints and therefore reduce the risk of knee and hip pain or injury to the athlete. However to still achieve the same amount of muscle activation and strength improvement at a lesser depth, the resistance must be increased. It stands to reason that these increases in resistance will, at some point, cause and equal amount of torque at the knee joint.

Statement of the Problem and Purpose of the Study

When there is an injury to the knee joint or an athlete is having knee pain, one of the first changes a coach can make is switching to a partial squat, over a full squat. Specifically, the coach will have the athlete perform the lift at less depth (partial squat) because they think that it places less stress on the knee (Gross, Credle, Hopkins, & Kollins, 1990). One problem with this is that limiting depth decreases the range of motion in the knee and hip joints which can lead to deficiencies in range of motion as well as strength of the hip musculature (Fry, Smith, & Schilling, 2003). A decrease in range of motion will place the athlete at a higher risk for injury if the joint is forced outside the range of motion in practice or competition (Schoenfeld, 2010). Another problem is that the forces on the knee are lessened during a squat at a higher depth with an equal load. However, in order to still achieve increases in strength, the weight must be increased. This change will increase the torque forces generated by the knee and hip (Escamilla et al., 2009).

The purpose of this research is to determine whether or not there is a difference in the magnitude of knee torque produced during a 1RM for a back squat at two depths. A full squat where the femur is at least 0°, or parallel to the ground, and a partial squat where the femur is at a 45° degree angle to the ground. A second purpose is to determine the effect of depth on maximum load lifted.

Research Question

1. Is there a difference in the magnitude of torque produced and load lifted between the two varying squat depths at maximal effort?

Null Hypothesis

There will be no difference in joint torque between the two squat depths at a maximal effort.

Significance of the Study

This research was done to show whether or not there is any significant difference in knee torque produced during a full and partial squat using the same subjects in the same study. All research up to this point has drawn comparisons about the varying depths at either sub-maximal loads, or comparing the two depths across multiple studies with different subjects and methodologies.

Delimitations

1. Eight current and former collegiate athletes participated in this research
2. The amount of weighted resistance used for each participant will vary.

Limitations

1. The effort of participants during the measured trials and whether or not it is truly maximal.
2. If the subjects perform other workouts outside the study, it could prevent them from achieving a maximal weight.

3. An illness may prevent a subject from attaining a true maximal weight.
4. If a participant has an injury, it can prevent them from getting a maximal weight.

Assumptions

1. The force plate is valid and reliable.
2. The VICON system is valid and reliable.
3. The barbell and weights are valid and reliable.
4. The depth variation is consistent with all subjects.
5. Reliability and validity of the equipment used should be assumed to be accurate but cannot be guaranteed.

Definition of Terms

1 RM: one repetition maximum (Cronin & Hansen, 2005)

Partial Squat: Squat position where the participant descends until the femur is 45 degrees to the platform (Bohannon, 1990)

Full Squat: Squat position where the participant descends until the femur is parallel to the platform (Bohannon, 1990)

Force Plate: are measuring instruments that measure the ground reaction forces generated by a body standing on or moving across them (Gullett, Tillman, Gutierrez, & Chow, 2009)

Vicon: Is a three dimensional motion capture system that uses a series of infrared cameras and reflective markers placed on a subject that are read and interpreted by the motion capture software (VICON Ltd.).

Torque: (Force · Moment Arm) The ability of a force to cause rotation on a lever, in the case of this study the levers are the joint segments and the force is the muscle force produced to extend the joint. Measured in Newton-Meters (N·m).

Hip:Knee Torque Ratio: Hip torque divided by knee torque

CHAPTER II

REVIEW OF RELATED LITERATURE

Introduction

The back squat is a dynamic strength movement that is present in most strength programs for athletes that require strength and power to aid in their performance (Gullett et al., 2009). It is for this reason that this research has chosen to examine the back squat. However, there are some factors that must be reviewed. This chapter will provide a brief background on the technique used for the back squat and highlight some of the purported benefits and detriments of the lift. The forces that are created by the body and exerted on it, as well as what factors can affect these forces will also be examined.

Technique

One factor that should be addressed before the rest of this review and will influence all of the following categories are the variations in technique used by certain athletes. Different athletes may utilize varying stances or positions for this movement based on their body type, which will be discussed in the following section, or by the goals of the athlete. The first style is the conventional or "Olympic" style squat. It is so named because it is the variation used by Olympic weightlifters to aid in the training for the snatch and clean and jerk lifts. The bar is place on the trapezius, a bit higher than the posterior deltoid. The feet should be parallel approximately shoulder width, with the toes pointed slightly outward (Escamilla et al., 2001). The second variation is the power lifting style of squatting. This variation is called the "power" squat and is performed with the same basic technique as the previous style, except that the bar now rest on the posterior deltoids and the feet are wider than shoulder width with the toes pointed outward to a greater angle (Delavier, 2010).

Benefits and Detriments of the Back Squat

The back squat is an extremely dynamic weight lifting exercise. Although it primarily targets the quadriceps, it also works the hamstrings, hip flexors, and most of the back musculature. It uses nearly the entire muscular system, and also works the cardiovascular system. It also aids in the development of thoracic expansion, therefore, respiratory capacity (Delavier, 2010). For those reasons, it is included in so many strength programs for a wide variety of athletes. It has many purported benefits, as well as a few claimed detriments, which should be examined to give a clearer view of whether this lift is the correct lift for a particular athlete, or type of athlete.

The benefits of the back squat have been very well documented in a variety of other literature reviews and over a period of decades. The most obvious benefit of the back squat is an increase in strength and power in the thigh musculature. However, compared to the leg press which almost exclusively works the quadriceps and hamstrings, the back squat is not limited to this area. As stated above, the back squat involves the muscular system of most of the body. Most notably the hip flexor muscles, as well as the erector spinae in the lower back. Therefore it can be seen as a much more efficient use of the athlete’s time to choose a back squat, rather than a leg press (Escamilla et al., 2001). Another demonstrated benefit of the back squat is joint stability.

When the back squat is performed, the joint becomes stronger and more stable throughout the practiced range of motion (Fry et al., 2003). This is important because a joint is more vulnerable and prone to injury when forced out of its normal range of motion. This increased joint stability and mobility can decrease the risk of injury for athletes (McGill, 1997). It becomes important for the athlete to perform the squat to a full depth to gain strength throughout the largest range of motion possible to minimize injury risk, as long as the lift is done with proper technique and appropriate level of difficulty (Zatsiorsky & Kraemer, 2006). Perhaps the most sought after benefit from the back squat is the increase in athletic performance.

There is a large portion of research has shown that an increase in strength in the back squat is positively correlated with vertical jump, 40 yard dash times, and power development. In the case of vertical jump, when strength is analyzed compared to proportionate body size, athletes with a higher absolute strength in the squat have a higher average vertical jump (Wisloff, Castagna, Helgerud, Jones, & Hoff, 2004). There is a similar correlation between back squat strength and sprint speed as well. In a study by McBride et al. in 2009, they demonstrated a significant correlation ($P < .05$) between higher relative squat strength and sprint speed in a range of distances from 10 to 40 yards, with a significant difference beginning to form at as little as 5 yards. This also demonstrates an increase in power through an increase in rate of force development. Interestingly, this increase rate of force development has been shown to be increased more effectively by training with half or partial squats. This is thought to be because athletes can train at a higher intensity and load for longer periods when compared to the full squat (Bazyler, Sato, Wassinger, Lamont, & Stone, 2014). With all of these benefits, there may be some risks associated with back squats at the loads necessary to achieve them.

There is very little reliable, scientifically supported research to demonstrate that a back squat may cause injury when performed properly. There are still concerns that should be addressed, however. There are a variety of factors to consider when prescribing a back squat for an athlete. These factors include, but are not limited to: weight lifting experience, strength level, sport type, and athlete body type. If it is an athlete that has little experience with resistance training, education on the proper technique and progression of training should be the highest priority. The technique of the athlete will also be influence by the athlete's body type. Athletes with longer femurs and a shorter torso will have more trunk lean which will place more of the load on the lower back and hip extensors such as the hamstrings. Conversely, having a longer torso and shorter femurs and a longer torso will create a more erect posture, which will place focus more on the quadriceps. Understanding theses variations will help coaches maintain the correct posture for their athletes and reduce the risk of injury due to incorrect posture (Delavier, 2010).

The risk of injury is always present when performing any type of athletic movement and the back squat is no different. However, with all the data that has been collected, it has been conclusively demonstrated that the risk of injury for a back squat is minimal and it is considered to be a safe way to increase strength (Rittweger, Mutschelknauss, & Felsenberg, 2003). Even during a maximal effort, the forces exerted by the muscles and the strain placed on the tendons are all at levels below the threshold to cause a rupture (Fry et al., 2003). The only demonstrated instances of an injury occurring during the proper execution of the squat were the result of an elite power lifter attempting to lift 2.5 times their body weight. In all other instances, injuries occurred under unsafe conditions when the athlete was using improper technique or an excessive load for their experience level (Escamilla, 2001). No matter how the back squat is performed, whichever technique is used whether correctly or incorrectly, there is still a large magnitude of force exerted by the muscles and joints to take the body through the movement.

Forces Created During the Back Squat

When the back squat is performed there are forces exerted both on the body and by the body. The greater the weight that is used for the lift, the greater the force that has to be exerted by the body in order to lift it. If the downward force is defined as negative and the upward force positive, the force of the bar exerts a negative force on the body. The feet also push in to the platform creating an upward ground reaction force that will be in the positive direction (Gross et al., 1990). During the eccentric, or descending, portion of the lift, the force created by the muscles is less than the force being exerted by the weight, so the net force is negative. When the lowest depth of the squat is reached and the lifter begins to change direction, the forces will reach equilibrium for a brief moment and the net force will be equal (Demilio, Gross, McGrain, & Plyler, 1989). Once the ascending or concentric portion of the lift begins, net forces become positive. During the concentric portion of the lift the forces produced by the muscles creates a force a positive force greater than the negative force of the weight (Escamilla, 2001).

The net positive force needed to perform the back squat successfully comes primarily from the quadriceps and back musculature. The hamstrings and hip extensor muscles are also activated when the squat is preformed to a depth that is below parallel due to the anterior pelvic tilt which adds to the activation of these secondary assisting muscle groups (Hartmann et al., 2013). The activation of these muscle groups creates a torque at both the hip, knee, and ankle joints. Collectively, these torques must create a net positive torque that is greater in magnitude to the force exerted by the resistance of the weight (Carcia, Kivlan, & Scibek, 2011). The torque that is necessary to overcome the resistance is affected by several key biomechanical factors rather than the weight of the resistance alone.

Factors that Determine the Forces Created during the Back Squat

The two main forces that affect the body during the back squat as previously mentioned are the negative force from the resistance of the barbell and the ground reaction force from the platform. (Gross et al., 1990). In order to successfully complete the lift the athlete must create a positive ground reaction force that is greater than the negative force from the barbell. To create a force great enough to lift the weight back to the starting position, the torque created at the ankle, knee, and hip joints must be positive (Demilio et al., 1989). The joint torque that needs to be created depends on several factors and may differ from athlete to athlete, even if the resistance remains constant.

The length of the shank, foot size and shoe type are all factors that could affect torque produced at the ankle and, to some extent, the knee (Baechle & Earle, 2000). The ankle and the aforementioned factors are primarily involved in stabilization and balance, however, they are not primary contributors to moving the barbell or the body so they will not be discussed in this paper. The factors that determine the torque that is produced by primary movement joints are the squat stance and body type/ body segment length. If athletes change their squat stance this changes the biomechanics of the squat due to changes in foot position, knee position, and the range of motion of the hips; as well as which secondary muscles become activated (Fry et al., 2003).

There are two main squat stances that are used by most athletes; the “power” style and “Olympic” style stances previously explained in the introduction. This section will explain why an athlete would choose one stance over another and how it can affect the biomechanics of the squat exercise. The Olympic squat is used by Olympic weightlifters because it is performed with a more erect posture and to full depth where the hamstrings briefly come to rest on the calves. The movement of the Olympic back squat, as well as the front squat, add specific strength for the athletes so supplement the actual Clean & Jerk and Snatch movement alone (Delavier, 2010). This stance minimizes shear forces on the spine and activation of the back musculature. It maximizes activation of the quadriceps and torque produced at the knee joint due to the knees being pushed forward in front of the. The hip extensors are also activated when the femur of the athlete is below parallel in relation to the platform (Escamilla et al., 2001). For a power lifting competitor, the squat itself is the competitive movement, not a lift to supplement strength, therefore, the only goal is to lift as much weight as possible. The stance for a power squat is different biomechanically, due to the difference in purpose for the lift. The power stance, with feet wider than shoulder width and pointed outward combined with the barbell resting lower down the back creates greater trunk lean and a depth that is no lower than parallel because that is all that is required for a successful lift in a competition(Simmons, 2007). The power squat maximizes activation of the back musculature as well as shear forces on the lumbar spine. The musculature of the groin also becomes an important secondary mover due to the width of the stance, instead of the hamstrings. This position creates more hip torque which puts less force on the knees. Splitting the torque between the two joints to share the load allows the athlete to lift more total weight (Escamilla et al., 2009). These two sports use a specific type of squat to attain a specific goal because both sports involve lifting weights. Not all sports involve lifting weights but many still benefit from increases in strength. Most athletes will have a squat technique and stance that differs from the two stances slightly, but will usually resemble one more than the other. This is due to comfort which is usually determined by the body type pf the athlete. Regardless of the style that is initially taught to an athlete, most will gravitate toward one style or the other, depending on what feels natural to them (Simmons, 2007).

The body type of an athlete will change the mechanics of the squat somewhat no matter which style they use to perform the lift. Body type refers to the differing proportionate body segment lengths. The length of the femur and torso are the main factors. Athletes with shorter femurs or a longer torso will have a more erect spine position which will place more emphasis on the quadriceps and most of the force for the lift will come from the knee joint, this variation will yield the highest magnitude of knee torque. If the athlete has long femurs or a short torso, there will be more forward trunk lean creating more shear force on the lumbar spine and placing more emphasis on the posterior chain i.e. the erector spinae and hip flexors, including the hamstrings (Delavier, 2010). Knowing this information about an athlete will help understand why an athlete will natural use one squat stance over the other. Prescribing the proper stance for the athlete will yield the best results for the development of the athlete and reduce the risk for injury (Zatsiorsky & Kraemer, 2006).

Conclusions

There has been a great deal of research devoted to the biomechanics of the back squat. The research for the back squat has examined the forces produced at the knee and hip throughout the range of motion. Due to this research it is known that the greatest amount of torque produced during a back squat is when the femur is parallel to the platform; increasing until the femur reaches that point, and decreasing slightly as it lowers past parallel until they reach the full range of motion, following the reverse pattern during the ascent phase (Escamilla, 2001). The other main factor that influences the magnitude of knee torque produced in this type of research is amount of resistance. The greater the resistance that is used, the larger the magnitude of torque produced (Hartmann et al., 2013).

One thing that has not been measured is the amount of torque produced at a parallel squat depth and half squat depth. As previously stated, when the weight remains constant, the torque produced is less at a higher depth. It is generally accepted that most athletes will have a higher 1RM for a partial squat than a full squat due to this fact. However, the amount of knee torque for a maximal effort at both depths has yet to be directly measured in the same study with the same participant performing both lifts. For this reason, the focus of this research will be to have the same athlete perform a maximal effort at both a half squat and a full squat on two separate sessions to determine whether or not the torque is equal or different, due to the supposed increase in 1RM from a full squat to a partial squat.

CHAPTER III

METHODOLOGY

Participants

Eight male athletes (standing height = 1.84 ± 0.07 m; mass = 87 ± 14 kg; age 23 ± 2.1) volunteered for the study. The subjects consisted of present and former competitive NCAA athletes experienced in weightlifting. Permission to conduct the study was obtained from the University of Northern Iowa Campus Committee for the Protection of Human Subjects. Informed consent was obtained from participants before the study began. At the time of the study all participants were healthy, with no complaints of knee, hip, back or other injuries.

Procedures

Collection took place in the Biomechanics Laboratory in the Wellness Recreation Center (WRC) at the University of Northern Iowa. Participants were instructed to wear tight fitting clothing for the purpose of marker visibility and placement while wearing their typical training shoes. It will be preferable to wear dark spandex which is non-reflective, but minor variations which do not interfere with data collection will be allowed.

Instrumentation

Each trial was recorded with a Vicon 370 three-dimensional (3D) motion analysis system (Oxford Metrics, Ltd., Oxford, United Kingdom). Six cameras captured the motions of 17 reflective markers, 15 attached to the subject and two to the barbell at a sampling rate of 200Hz. The Vicon system calculated 3D coordinates for the markers.

The ground reaction forces and torques exerted on the right foot were measured with an AMTI force plate (Advanced Mechanical Technology, Inc., Watertown, MA) at a sampling rate of 2000 Hz.

The 3D coordinates of the markers were expressed in terms of an inertial reference frame. The origin of the reference frame was at ground level, at the front, right corner of the force plate in relation to the subject facing forward. Its axes were defined by vectors **X**, **Y** and **Z**. **X** was horizontal, and pointed toward the left; **Y** was horizontal and pointed backward; **Z** was vertical, and pointed upward.

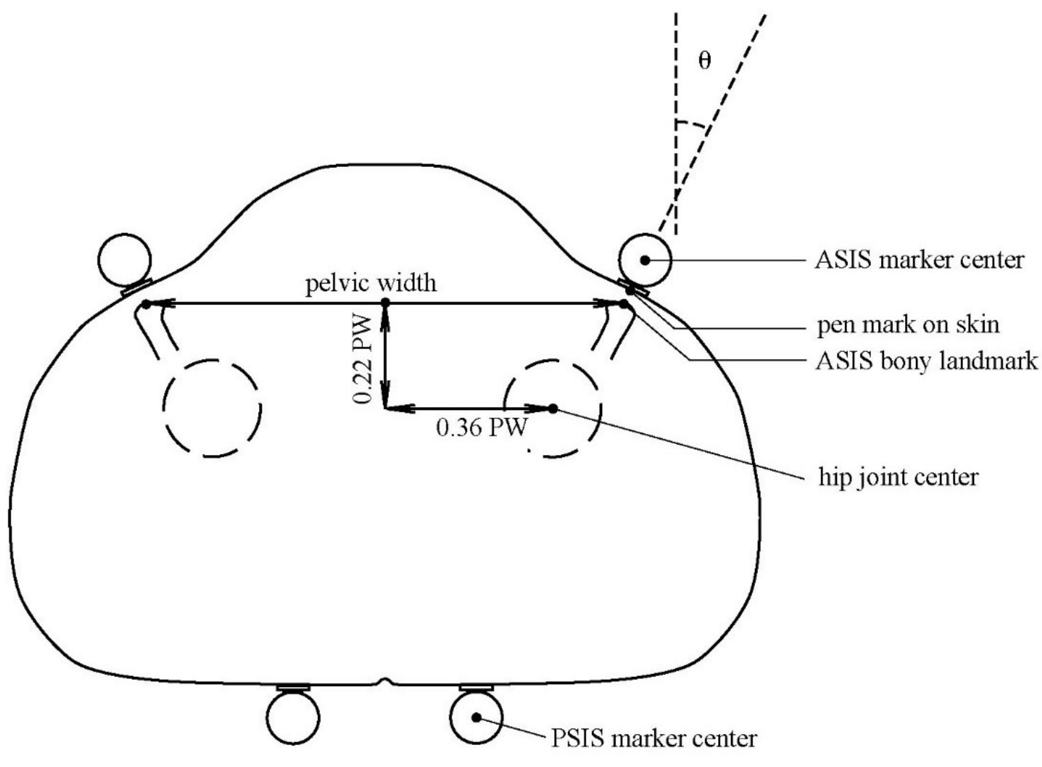

Figure 1 A visual representation of the pelvis cross-section that contains the centers of the hip markers (ASIS and PSIS). The hip joint was estimated to be at distances of 36%, 22%, and 30% of pelvic width laterally, posteriorly, and caudally, relative to the midpoint between the ASIS bony landmarks. Photo and method used with permission of B.W. Meyer (2005).

The reflective markers were placed on each end of the barbell and the body on the following landmarks: One anterior and two posterior on the surface of the trunk at the level of the suprasternal notch; surfaces of the left and right posterior superior iliac spines (PSIS); surfaces of the left and right posterior anterior iliac spines (ASIS); two lateral markers on the left and right iliac crests; two markers on the medial and lateral sides of the femoral epicondyles on the right leg; medial and lateral malleoli on the right leg; heel and toe of the right foot, on the surface of the participants shoes. All participants were wearing weightlifting shoes with a solid raised heel. The posterior suprasternal markers were averaged to create a single point. This point was then averaged with the anterior suprasternal marker to estimate the suprasternale position. The hip joint center was estimated using the method shown in figure 1 above and outlined by Bush and Gutowski (2003). The knee and ankle joints were calculated as being the midpoint between the medial and lateral markers. The heel and toe marker were used to create the foot segment. Marker configuration is courtesy of Dr. Ben Meyer (2005). The markers were assumed to be symmetrical in relation to the corresponding marker on the opposite side of the subject.

Protocol

Participants self-reported their 1RM back squat. The participants self-reported 1RM will be used to calculate the percentages for three warm-up sets and starting weight. Participants will be instructed to perform a warm up consisting of their choice of ~3 minutes of light jogging or stationary bike and will then be given ~5-10 minutes to perform their typical warm up to facilitate optimal performance for the individual. The participant was escorted to the squat standards with the barbell in place. There was a warm up set of 10 repetitions at 50% of the self-reported 1RM. Another set of 5 repetitions at 75% of the self-reported 1RM.

After the warm-up, subjects will rest for 5 minutes and the bar will be loaded to 85% of 1RM. Subjects performed 3 repetitions. They rested for up to five minutes. Then they began collected trials at one repetition. This was repeated until the participant either failed to complete the squat at the required depth, or they felt that they were very near their 1RM and could no longer increase the weight. Repetitions were repeated under each of the conditions; partial squat and full squat. The order of the treatments will be randomly assigned, then they will perform the next variation the following session. Subjects will rest 1 week between treatments.

For the full squat trials each participant was instructed to squat as deep as possible, at minimum when the femur was parallel with the force platform at the lowest point of the descent. This constituted a complete full squat trial.

For the partial squat each participant was instructed to squat until they felt an elastic cord stretched across below them at a point where their femur was 45 degrees with the platform. The chord was set up using an angle measurement taken prior to the beginning of the trial collection to determine the proper height. The spotter also gave a verbal cue of an “up” command when the proper depth had been reached. This constituted a complete partial squat trial.

Data Analysis

After collection data were exported and smoothed at a rate of seven Hz using quintic spline functions fitted to the X, Y, and Z coordinates of each marker (Woltring, 1986). Custom software was used to analyze the 3-D and force plate data and calculate the joint centers and joint torques using inverse dynamic analysis. Using the procedures outlined by Dapena (1978) instantaneous location of each segment was computed. The leg segment parameters were taken from de Lava (1996). Then the proximal joint force and torque exerted by the proximal segment on the distal segment of each joint was calculated using the procedure described by Andrews (1974, 1982).

After the hip and knee torques were calculated the data points were analyzed by SPSS statistical software to determine whether there were any statistically significant differences in the levels of torque between depths. A repeated measures MANOVA was used to compare the depth effect on torque between the full and partial squat trials. A paired samples t-test was used to test the significance of the increase in barbell load from full to partial squat trials.

CHAPTER IV

RESULTS

Descriptive statistics of demographic data can be found in Table 1. Descriptive statistics of all performance variables at both depths at similar angles can be found in Table 2. Descriptive statistics of all performance variables at both depths at the greatest depths can be found in Table 3. The first repeated measures MANOVA demonstrated that there was no depth effect ($F(3,5)=4.7$, $p=0.065$) when comparing the full and partial squats at similar joint angles (45°). There was also no depth effect when comparing the bottom positions ($F(3,5)=0.2$, $p=0.92$). The paired samples t-test indicated that the partial squat resulted in significantly greater bar loads compared to the full squat ($t(7)=12.9$, $p=0.001$).

All data are reported as an extension torque at the instant of the subject reaching the required depth for both the full and partial squat trials and also 45° for both trials. In the full squat trials this depth is 0° (thigh parallel to floor), and 45° (angle of thigh to floor) in the partial squat trials.

Table 1

Descriptive Statistics for demographic variables.

Variable	N	Mean	SD
Mass (kg)	8	86.9	10.8
Stature (m)	8	1.85	0.05
1RM Full (kg)	8	144.6	34.1
1RM Partial (kg)	8	206.2	39.1

Table 2

Descriptive statistics of performance variables by depth at similar angles (45°).

	Full Squat (45°)		Partial Squat (45°)	
Variable	Mean	SD	Mean	SD
Knee Torque (Nm)	151.5	90.6	217.6	113.1
Hip Torque (Nm)	189.2	83.9	222.1	140.0
Hip:Knee	2.6	3.1	1.4	0.9

Table 3

Descriptive statistics of performance variables by depth at the greatest depths.

	Full Squat (0°)		Partial Squat (0°)	
Variable	Mean	SD	Mean	SD
Knee Torque (Nm)	246.9	136.4	217.6	113.1
Hip Torque (Nm)	215.8	109.6	222.1	140.0
Hip:Knee	1.3	1.2	1.4	0.9

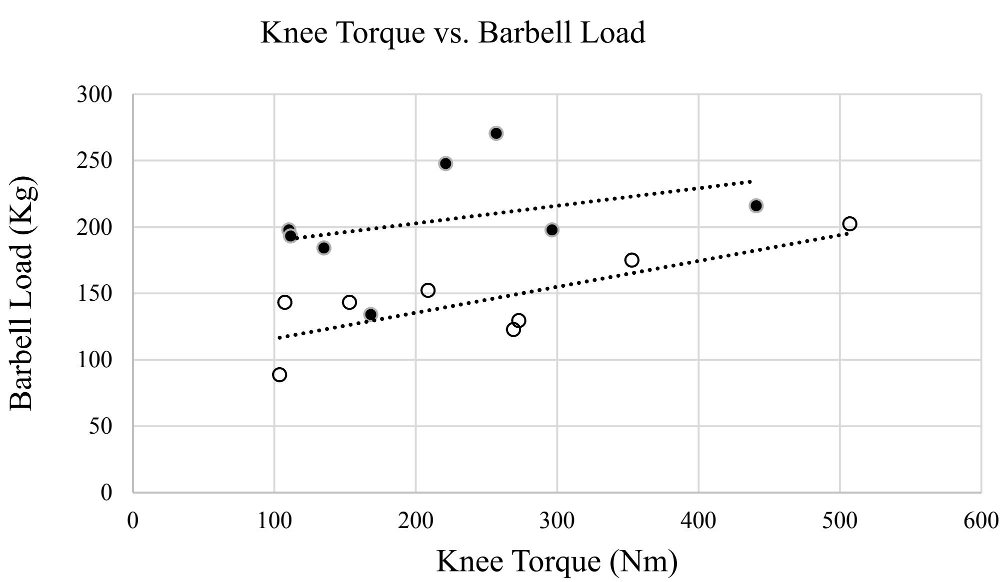

Figure 2 The black points represent the partial squat and the grey points the full squat, the amount of barbell load required in order to produce various amounts of knee extension torque in the full and partial squats.

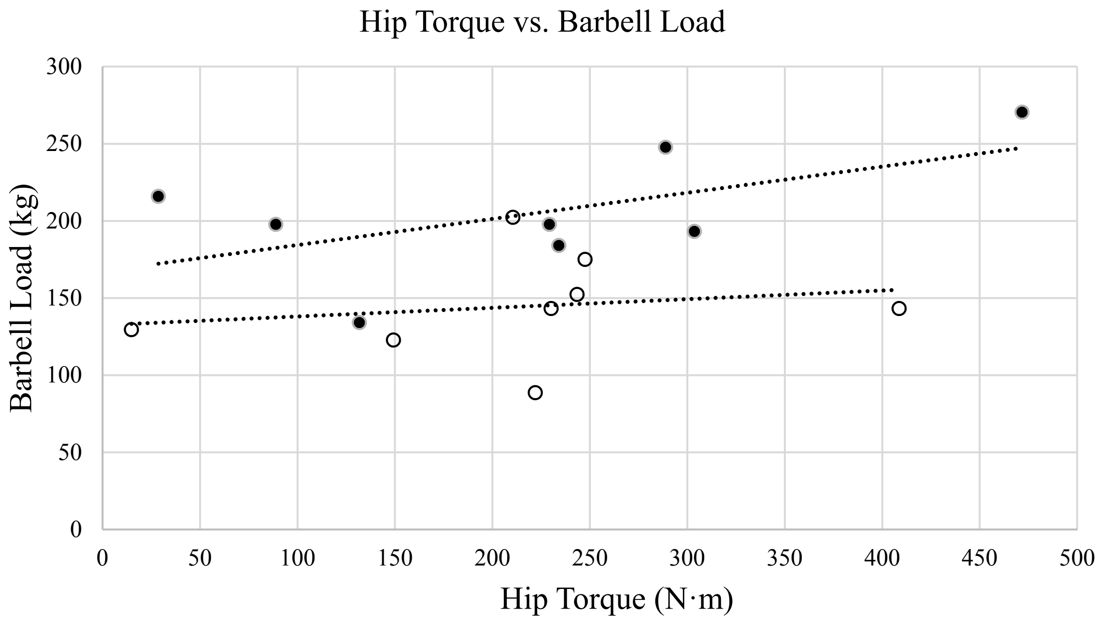

Figure 3 With the black points representing the partial squat and the grey points the full squat, the amount of barbell load required in order to produce various amounts of hip extension torque in the full and partial squats.

CHAPTER V

DISCUSSION

The results show that there is no significant difference in hip and knee torques at the bottom depth of the partial and full squat trials during a 1RM. There are no published articles examining a maximal effort partial squat to a maximal effort full squat in the same study, using the same participants. The published literature that has been referenced to this point has compared the torques created during a full squat at varying joint angles during the same trial using the same barbell load, instead of separate trials for each depth in the same study. There was also no literature found comparing the percentage increase or total load increase when performing a maximal effort partial squat (thigh 45° in relation to the floor) compared to a maximal effort full squat (thigh 0°, or parallel, to the floor).

Most research for clinical purposes has been ruled out for comparison due to the fact that this research was done on healthy participants for the purposes of performance, not rehabilitation. Clinical subjects with a hip, back, or knee injury would be fundamentally different compared to the subjects of this study.

It is also difficult to compare knee and hip torques from different studies due to differences in body mass, methodologies, barbell load, and the individual subject's technique variations with emphasis on either hip of knee torque. With that in mind, there are four main articles that will be used for comparison to this data: Escamilla (2001); Hartmann et al. (2013); Escamilla et al. (2001); Gullet et al. (2009).

The above research has stated that at the same barbell load, knee and hip torques will be greater as depth increases due to an increase in the length of the moment arm at the joint centers from the center of pressure. Joint forces will be at their peak when the thigh is parallel to the floor (Escamilla, 200l). This held true for the subjects of this study, with the joint torque increasing at the hip and the knee until peaking when the thigh was parallel to the floor. However, it was possible for the subjects to reach the same torque values during the partial squat with a substantial increase in barbell load.

In a literature review done by Hartmann et al. (2013) they drew comparisons between the partial squat, which they referred to as a quarter squat at the same comparable depth as this study (50° compared to 45°), and a full deep squat (90° of knee flexion and greater). Although they drew comparisons across multiple studies with different participants, they concluded that statements against the deep squat (below thigh parallel to ground) were unfounded. When the deep squat was performed correctly and with proper supervision, it produced superior joint and muscle tissue adaptations when compared to the partial squat. This differs from the conclusions drawn by Escamilla (2001) and Escamilla et al. (2001) which stated that the deep squat could increase injury potential to the cruciate and collateral ligaments, however, they cite no specific case or epidemiological study in which an injury of this type occurred. In the comprehensive literature review done by Hartman et al. (2013), as well as in preparation for this study, no examples could be found where a deep back squat caused injury when performed correctly.

In this study the average increase in barbell load for the partial squat compared to the full squat was 70.2 kg or a 60.5% increase in barbell load. It is of importance to note that these participants did not train the partial squat, so these increases were without prior training. Although they were closely supervised, the participants were hesitant to reach a point that was as near failure as during the full squat trial. The participants cited the reason being excess discomfort from the added spinal load due to the increase in barbell load, with the actual squat movement having less hip and knee joint discomfort or effort than the full squat.

The large increase in the percentage of barbell load required to achieve the same levels of hip and knee torque should be considered by anyone that would prescribe partial squats to avoid excess knee and hip torque, either due to injury, or for injury prevention. Hartmann et al. recommended full squats with a smaller load even when rehabilitating an injury. The full squat remains preferable even at more submaximal levels to maintain as much range of motion as possible for the athlete. Although at the same barbell load the partial squat will have less knee and hip torque, there will be a decrease in the range of motion which could possibly decrease flexibility of the joints and reduce joint and muscle strength adaptations through the rest of the range of motion that is not being utilized.

Another interesting note is that there was a smaller increase in hip torque when changing from the full to half squat as there was with knee torque (7 N·m compared to 30 N·m respectively). Although these changes are both small and not significant ($p \geq .05$), it does support the subjects' notes of an increase in discomfort from the increase in spinal load. They changed their mechanics to maintain a more erect posture, decreasing the shear force on the lumbar spine and shifting the center of mass closer to the heels. This change in mechanics is supported in the study by Gullet et al. (2009), although that study compared the mechanics of a back squat to a front squat, the mechanics of shifting the barbell toward the heels and maintaining a more erect posture are still similar in comparison.

This could be useful in some instances for athletes that are looking for that type of specific adaptation, specifically powerlifters or Olympic weightlifters. It should be noted however that Hartmann et al. also showed that the full squat still favored positive hip and knee joint as well as muscular development when compared to the partial squat. This should be considered when prescribing the type of squat to an athlete.

Conclusions

This study was undertaken to better understand the relationship between the full squat and partial squat when performed by the same participant at a maximal level. With this research in combination with the previous research it becomes clear that the full and partial squat do have some fundamental differences.

One such difference is the change in mechanics of shift the center of mass back toward the heels during the partial squat in order to handle the substantial increase, 60.5% average, in barbell load over the full squat. The increase in load also excessively loads the athlete's spine without a significant increase in knee or hip torque and combined with the discomfort of the participants while performing the partial squat, the full back squat will yield the same level of hip and knee torque at lower barbell loads that the athlete's musculature is better adapted to handle.

Athletes wishing to increase their maximal knee torque and increase their adaptions to an increased spinal load may still wish to perform a partial squat, however, full squats are still better suited to increase strength of the leg musculature and joints. The best results would be achieved by using the partial squat to supplement the full squat, not replace it (Bazyler et al., 2014).

Even for an athlete with a knee injury, practitioners should consider the possibility that full squats at a smaller barbell load are still preferable to a partial squat due to the maintaining of the joints flexibility and full range of motion, although it will depend on the type and severity of the injury.

Recommendations for Future Research

This research has demonstrated the hip and knee torques between a 1 RM full and partial squat as defined by this study. There are, however, more questions that could be answered by further research. One such example would be variations on the thigh angle for the partial squat. Another area of interest could be testing the two depths at submaximal levels of barbell load to see if the joint torques change at the same rate when barbell load is changed. Further study could also look in to the consistency of the percentage increase of 1RM when switching from full squats to partial squats. These are only a few examples of future studies that could be completed.

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