2017

Comparison of forward lean during Bulgarian split squat at high and low box heights

Craig Konrardy
University of Northern Iowa

COMPARISON OF FORWARD LEAN DURING BULGARIAN SPLIT SQUAT AT HIGH AND LOW BOX HEIGHTS

An Abstract of a Thesis

Submitted

In Partial Fulfillment

of the Requirements for the Degree

Master of Arts

Craig Konrardy

University of Northern Iowa

December 2017

ABSTRACT

This study examined the difference between forward lean while performing the Bulgarian Spilt Squat at different box heights of 40 cm and 20 cm. The study also compared the maximal force output of the front foot during the BSS at the different heights.

Fifteen male athletes (standing height=180.73 ± 6.67 cm; mass= 80.45 ± 7.63 kg; age=18.55 ± 0.69 years) volunteered to complete the study. The participants performed three repetitions of each leg at two different heights of the Bulgarian Split Squat with 30% of self-reported back squat 1RM. Participants stood on a force plate to report maximal force during each repetition while being recorded to generate a forward lean angle.

The box height of 20 cm generated lower force output (1121.86 ± 197.11 N) and a smaller degree of forward lean (19.38 ± 1.21 º) compared to the box height of 40 cm. The box height of 40 cm resulted in greater significant force output of 1163.15 ± 194.44 N and a greater significant forward lean of 27.56 ± 1.86 º.

COMPARISON OF FORWARD LEAN DURING BULGARIAN SPLIT SQUAT AT HIGH AND LOW BOX HEIGHTS

A Thesis

Submitted

In Partial Fulfillment

of the Requirements for the Degree

Master of Arts

Craig Konrardy

University of Northern Iowa

December 2017

This Study by: Craig Konrardy

Entitled: COMPARISON OF FORWARD LEAN DURING BULGARIAN SPLIT SQUAT AT HIGH AND LOW BOX HEIGHTS

has been approved as meeting the thesis requirements for the

Degree of Master of Arts

Date	Dr. Jacob Reed, Chair, Thesis Committee
Date	Dr. Robin Lund, Thesis Committee Member
Date	Dr. Fabio Fontana, Thesis Committee Member
Date	Dr. Patrick Pease, Interim Dean, Graduate College

ACKNOWLEDGEMENTS

I would like to thank my advisor, Dr. Jacob Reed, for his guidance through the course of this project and my graduate career. With his guidance and insights have improved the quality of my research and thesis. I am thankful for his wisdom and willingness to assist me with my project.

I would also like to thank Dr. Robin Lund and Dr. Fabio Fontana for serving on my committee. This thesis project would not be to the quality it is without their help.

I also want to thank Spenser Popinga and the Waterloo Black Hawks Hockey Team for letting their athletes be used as the participants. Also, thank you to all of the athletes for agreeing to participate, their time, and cooperation during data collection. Without Spenser and the Black Hawks this project would not have been accomplished.

Finally, I would to thank my parents Jim and Rita for being their roommates while they let me chase my educational goal. Without their support, I would not have been able to continue my education, let alone finish this program within 18 months. I want to thank the rest of my family: Hannah, Justin, and Alexis for having to deal with me after the long days and nights of school and this project.

TABLE OF CONTENTS

LIST OF TABLES

TABLE PAGE

LIST OF FIGURES

FIGURE PAGE

CHAPTER 1

INTRODUCTION

The most popular way to create lower body strength and hypertrophy is with the use of the conventional squat (Chang, Chang, Lin, & Ho, 2016; DeForest, Cantrell, & Schilling, 2014). When programing, the squat is viewed as the centerpiece for increasing lower body strength. The conventional squat is a bilateral movement, with a load rested on the upper back. To perform the lift, the athlete uses hip and knee extensors to generate force in order to lift the load from a low spot of legs being parallel to the ground (Ardison, 2017).

A major problem with the squat is its potential to lead to injuries which can in turn prevent athletes from continued training. It has been shown that a forward lean in the squat can lead to lumbar spine injuries of the back (Fry, Smith, & Schilling, 2003; Meyer, 2005). If the injuries or pain are too great it can lead the athlete to stop training in fear of increasing the pain, or making the injury worse (Risch et al., 1993). When this is the case atrophy could occur, potentially resulting in a loss of strength and/or competitive performance.

Unilateral exercises may provide a mechanism to avoid injury, while still improving strength and competitive performance. The only shortcoming is that there is not enough data suggesting unilateral strength training can improve strength and power (K. W. McCurdy, Langford, Doscher, Wiley, & Mallard, 2005). Speirs (Speirs, Bennett, Finn, & Turner, 2015) suggests that a Bulgarian Split

Squat (BSS) can produce 85% force on a single leg. With the BSS generating those forces, it leads to speculation that the BSS exercise could be used as alternative to the conventional squat.

The BSS is completed with one foot elevated, typically on a bench. The athlete finds their balance by moving the lead leg to a comfortable position and begins to descend by flexing the lead leg at the knee. The movement is similar to a lunge where the athlete wants to lower the elevated knee towards the ground until the front leg is parallel with the ground. The athlete pushes through the heel and returns to the starting position (Boyle, 2015).

Angel Spassov, who is considered the founder of the BSS, suggests that he only has had his athletes train with their rear foot elevated on weight plates or boxes six inches high. He suggested that this was because any higher could create a greater load on the lumbar spine, suggesting more injuries to the back (Goss, 2013).

With the lack of research, there is a possible way of being able to strengthen the legs without putting the lumbar spine at risk. Dr. Meyer suggests that this is possible by doing a split squat with the rear leg elevated (Meyer, 2005). To the authors knowledge, there has been no research on the height of the rear foot while performing the BSS.

Purpose Statement

The purpose of this study was to investigate the difference in torso flexion and vertical force during the BSS at 40 cm and 20 cm box heights.

Research Questions

1. Is there a different degree of forward lean on a higher box height compared to a lower box height?
2. Does the front foot have similar vertical force outputs on both box heights?

Hypothesis

It is hypothesized that using a lower box height will have no difference in degree of forward lean between the different box heights (null hypothesis). A secondary hypothesis is that using a lower box height will produce similar amounts of force as the foot being higher.

Limitations

Possible limitations with this study include:

1. Participants that are unfamiliar with this study could be uncomfortable; therefore, they may not entirely go through a full range of motion. Several repeat trials were performed to establish an average of forward lean and decrease outliers.
2. All participants are not of the same height, causing issues with front foot placement. All subjects began with the front leg just above 90° to keep the knee from extending over the toes.
3. The measures of forward lean were recorded and exported onto a computer in Maxtraq for the angle to be digitized. These measures were subject to human error.
4. Foot placement was self-selected which can lead to potential differences of forward lean between participants.
5. 40 cm box height may impact those who are shorter, potentially effecting the results.

Delimitations

Our ability to generalize the results of this study are due to:

1. The athletes recruited as subjects had been exposed to the procedure prior to testing.
2. The subjects for this study were young healthy athletes aged 18-21 years.

Assumptions

1. All subjects gave their best efforts throughout the testing protocol.
2. All subjects provided truthful answers on the informed consent questionnaire.

Terms

1. Bulgarian Split Squat: Person standing with one foot in front of the body and the other trailing, finding balance. The rear leg will be lifted onto an object, so the front foot is the only thing in contact with the floor. The person will then descend vertically trying to touch the rear knee to the floor or the front knee parallel to the ground.

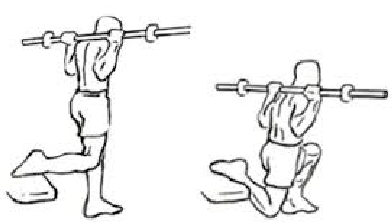

Figure 1. Example of Bulgarian Split Squat

2. Lumbar Spine: Largest moveable vertebrates of the spinal column. It is what most people know as their lower back. It consists of five vertebrates L1-L5. Is connected to the thoracic vertebrates(ribs)
3. Box Height: Fixed height that the person will rest their rear foot of during a Bulgarian Split Squat. Usually a bench or boxes stacked together
4. Load: Amount of force that is put onto something.
5. Vertical Force (F_z): sagittal-plane component of a force (acting about a body); orthogonal both to horizontal (transverse: F_x) and forward (frontal-plane: F_y) component (Vertical Force, 2009).
6. Forward Lean: Deviation of the trunk relative to vertical and can result from hip and knee flexion (Donnelly, Berg, & Fiske, 2006).

Significance of the Study

The research study is important as it may provide insight into the characteristics of the BSS. This study may help strength and conditioning coaches in determining elevation of the rear foot during the BSS.

CHAPTER 2

REVIEW OF LITERATURE

Unilateral Versus Bilateral

The main exercise related to creating lower body strength and hypertrophy is the conventional squat (Chang et al., 2016; DeForest et al., 2014). The conventional squat is a bilateral movement, with a load rested on the upper back. To perform the lift, the athlete uses hip and knee extensors to generate force to lift the load from a low spot usually around the legs being parallel to the ground (Ardison, 2017).

Resistance training protocols for athletes have been developed around creating a strong base for movements, generally by the way of the squat (McCurdy et al., 2010). But McCurdy et al. also states that lower body movements such as running, hitting, jumping etc. are predominantly unilateral or single leg bearing. The theory then arises that to most effectively improve athletes and athletic performance, resistance training should mirror the mechanics and forces of the skills being performed (Baechle & Earle, 2000). If the athletes are only training bilaterally with the squat, then they are not improving sport specific skills required to enhance their competitive sport performance.

Athletes that are training unilaterally with a BSS, incur a force on their lead foot equal to about 85% of the total load (Speirs et al., 2015). With the lead foot taking on the load, it generates more force to move the weight back up. While in conventional squatting, the total load is absorbed across both feet, meaning that both feet absorb around 50% of the total load. When doing the BSS each individual leg will experience more force compared to a bilateral squat.

Some practitioners believe that if an athlete training unilaterally can generate more force in each leg by training unilaterally, it should take precedence over bilateral movements. The logic behind this theory is called the Bilateral Deficit, or the summed forces of unilateral movements is greater than that of the bilateral forces (Bobbert, Graaf, Jonk, & Casius, 2006). In theory, athletes generate more force with one leg, so therefore they should generate twice as much force with both legs compared to one leg.

Justification

This literature review is important in understanding why most strength training protocols still have the squat as the centerpiece for lower-body strength. While looking at strength periodization, conventional squats are dominant while unilateral movements are considered an accessory. It was stated earlier, training unilaterally can generate more force in each leg compared to bilateral training.

Review of Literature

When discussing unilateral versus bilateral training, Mike Boyle is universally considered an expert on the topic. He is famous for being a strength and conditioning coach that refused to use the back squat in any of his training, but instead programs the BSS (Boyle, 2015). The BSS requires an athlete to assume the lunge position, raise the rear leg onto an elevated platform, thus isolating the front leg. As stated earlier this can generate 85% of the load onto the lead foot (Speirs et al., 2015). Boyle took a group of individuals through 6-weeks of training and had then tested the BSS. Using 50% of each individual back squat 1RM, the individuals completed the exercise as many times as possible. The highest 1RM was 460lbs, which put 50% for this individual at 230lbs for the BSS. This individual completed the exercise for 14 repetitions. Boyle claims that there is no way in six weeks an individual can train for the back squat and complete 14 repetitions of their 1RM. This would put the individual's new 1RM at 675 lbs. Currently, there is little to no research on unilateral movements improving strength and or power in athletes (Negrete & Brophy, 2000).

While viewing resistance training programs bilateral movements still dominate unilateral movements as core lifts. Unilateral movements such as lunges, step-ups, and single squats receive less emphasis or are accessories (Jones, Ambegaonkar, Nindl, & Smith, 2012; McCurdy et al., 2005). These exercises are viewed as plyometric exercises compared to actual strength building exercises (Wilson, Murphy, & Giorgi, 1996).

When comparing summed unilateral forces to bilateral forces of the leg, unilateral is greater, which is known as the bilateral deficit (Bobbert et al., 2006). When jumping on one leg individuals can generate forces of 58.5% per leg, thus greater combined forces than that of the two-legged jump (Soest, Roebroeck, Bobbert, Huijing, & Schenau, 1985). Assuming, both legs can generate the same amount of force, both legs together should be able to produce forces of 117% two-legged jump. According to Bobbert et al. (2006) the dominant leg generates 0.1 J/Kg more than the non-dominate leg. With this being the case, the percentage will not be as high, but forces should still be greater than what are originally produced.

Reasons for the bilateral deficit can be answered by evaluating what is happening at the joints and take-off or launch times. Bobbert et al. (2006) used angles of the hip, knee, and ankle to differentiate between unilateral and bilateral jumps. It was calculated that total joint work was 78% of the one leg jump for the two-legged jump. The difference was because the knee and ankle performed substantially less work when compared to the one-legged jump. Soest et al., (1985) results concluded that single legged jumps had greater work than the bilateral jumps. The less work on the joints is attributed to the total work being distributed between two legs and not just one. They also showed that the change in mechanical energy of the center of mass during push off was 4.9 J/Kg for two-legged and 4.3 J/Kg for one-legged. The combination of differences in joint work and change in mechanical energy could be the cause of the bilateral deficit in jumping.

Bilateral deficit is not only seen in jumping and countermovement jumping. Assmussen and Heeboll (1961) showed isometric forces in knee extension of bilateral movements are less than the sum of unilateral movements. This study was then repeated years later and yielded the same results, bilateral forces are less than the sum of the unilateral forces (Schantz, Moritani, Karlson, Johansson, & Lundh, 1989).

When comparing a unilateral resistance training program and bilateral resistance training program the results show no significant benefits of either program (McCurdy et al., 2005). The only significant finding of the study is a unilateral program generates significantly greater vertical jump height compared to the bilateral training program. However, the results did show that for men, the bilateral training did increase strength in a bilateral squat and unilateral squat more than the unilateral group. Whereas females in the unilateral group performed better on the bilateral squat, and worse on the unilateral squat as compared to the bilateral strength group. For men, unilateral trained athletes had lower scores than the mean for both bilateral and unilateral squat. For females, bilateral group performed under the mean on bilateral squat, while unilateral performed under the mean for unilateral squat.

The comparisons of bilateral to unilateral lead to the assumption that the same muscles are being used the similarly during each movement. The bilateral squat and a unilateral BSS use the same musculature to complete the tasks, quadriceps, hamstrings, and the glutes. When completing the exercises, Jones et al. (2012) described muscle activation between the bilateral squat and BSS, through sEMG. The quadriceps (represented by the Vastus Lateralis) and hamstrings (Biceps Femoris) had more activity in the squat compared to the BSS

(0.61 vs 0.6 and 0.18 vs 0.16). However, the glutes (Gluteus Maximus) demonstrated greater activity in the BSS (0.12 vs .01). Their conclusion showed that activity was similar, but the amplitudes were different in the muscles. Other research has found different results. Schantz et al. (1989) used EMG data for their study to examine the works of Asmussen and Heeboll measuring unilateral and bilateral isometric knee extension. Schantz et al., results showed that EMG activity had no systematic differences between unilateral and bilateral.

Bilateral deficit suggests that the summed forces of each individual leg is greater than the force of both legs together and not a well-documented phenomenon. There are many reasons on why the body cannot express the same amount of force with both legs as done with one. For some people, they choose to ignore bilateral deficit. Due to the lack of research on unilateral training resulting in strength and power, causes these movements to be ignored as core exercises in strength and conditioning. As stated, muscle activity is similar in both movements which leads to the thought that maybe they both can produce identical results. The differences between unilateral and bilateral training are not as far apart as previously thought, but both are not researched the same. Unilateral training is viewed as accessory or plyometric based while bilateral training is considered core or centerpiece lifts. Both training exercises end up giving athletes the same tools to succeed, whether it is strength, speed, jumping, running etc. Therefore, conventional squats should stay in exercise programming, but unilateral movements need to be used more often than what they are.

Anatomy of the Hip

When preforming the BSS one leg is out in front of the body while the other is elevated on a box behind the body. Athletes then lower the body trying to touch the elevated legs knee to the ground or until the front leg is parallel with the ground. Completion of this exercise properly and safely requires usage of the hips. An athlete must be flexible enough to put their body in those positions while going through a wide range of motions. They also must have the balance to complete the exercise without rotation of the torso in the transverse plane that could cause injury.

Being able to squat into a proper position puts a lot of pressure on the hips or the pelvic girdle. At the bottom of the exercise one side of the hips is flexed while the opposite side is extended. To completely understand how to perform the BSS, understanding the actions of the hips is required.

Justification

This review of literature is important because the knowledge of the hip's anatomy is necessary in understanding what cause the forward lean while squatting. The hip is the main focal point of the exercise and is the joint that generates torso flexion and extension. Having a knowledge of the hips anatomy can elaborate on why there is a forward lean. After this review of literature, the reader will have a knowledge of the hips process while the BSS is being performed.

Review of Literature

The pelvic girdle is what is often referred to as the hips and connects the limbs of the appendicular skeleton to the axial skeleton (Hamill & Knutzen, 2008). Comparisons of the pelvic girdle and the shoulder girdle are due to both being synovial ball and socket joints, but the pelvic girdle bigger and heavier than the shoulder girdle. It is heavier because it requires more of load bearing and is required to carry the weight of the torso plus the external loads (barbell during a squat) while exercising. Along with bearing greater loads it has larger bones and muscles that connect at the pelvic girdle compared to the shoulder girdle (Whiting & Rugg, 2015).

The pelvic girdle consists of the sacrum and coccyx. The hip joint is where the head of the femur fits into the acetabulum. It can move through all planes of motion making it a ball and socket joint. The pelvic girdle connects the lumbar spine to the lower limbs with the sacrum being fused vertebrate. With connection to the lumbar spine the pelvic girdle is part of the curvature that is part of the spinal column. It aids the lumbar spine in shock absorption, balance, and movement through wide ranges of motion (Hamill & Knutzen, 2008; Whiting & Rugg, 2015).

Being a synovial ball and socket joint the hip is moveable throughout a wide range of motions, while being a stable joint. The main joint of the hip is the coxofemoral (coxal) joint. The coxal joint is where the femoral head is attached in the acetabulum. The coxal joint aids with the flexion, extension, and hyperextension of the torso in the sagittal plane. The flexion or extension is caused by the pelvic girdle rotating anteriorly or posteriorly. With the pelvic girdle rotating anteriorly resulting in torso flexion while posterior rotation results in extension of the torso. Chronic anterior rotation of the pelvis can lead to lumbar lordosis or low back pain. While it does generate flexion of the torso it also creates hyperextension of the spine. This hyperextension increases the load that is on the lumbar vertebrate. The coxal joint has the ability of abduction or adduction in the frontal plane. Finally, the coxal joint generates rotation in the transverse plane, causing the torso to rotate medially or laterally (Whiting & Rugg, 2015).

There are many muscles that cross over the pelvic girdle and the coxofemoral joint, which provide stability and strength. The starting position of the BSS with the rear elevated leg places the coxal joint in an extended position, while the opposite coxal joint of the front leg in a small flexed position. The rear leg recruits the gluteus maximus, semitendinosus, semimembranosus, biceps femoris long head, and the adductor magnus. With the front leg recruits the psoas major, iliacus, pectineus, rectus femoris, adductor brevis, adductor brevis tensor fascia lata, sartorius, and the gracilis. Rotation of the knee will result in adduction or abduction of the coxal joint. If there is abduction (knee externally rotated) there will be requiring more force from; gluteus medius, gluteus minimus, tensor fascia lata, gluteus maximus, psoas major, iliacus, and Sartorius. While if there is adduction (knee internally rotated) will require more force from; pectineus, adductor brevis, adductor, longus, adductor magnus, and gracilis (Whiting & Rugg, 2015).

Knowledge of the hip anatomy and coxofemoral joint are essential to understanding the motion of the BSS. Without the knowledge, it would make it hard to understand why the exercise selection is used in a weight training protocol. It also helps understand why the body is doing what is doing while performing the exercise.

Forward Lean

While performing the conventional squat, athletes anteriorly rotate their hips creating a flexion of the hips. This flexion also generates hyperextension of the lumbar spine. This flexion is known as forward lean. In other words, the forward lean is, “the deviation of the trunk relative to vertical and can result from hip and knee flexion” (Donnelly et al., 2006).

Not having forward lean is almost impossible while squatting due to the need to displace the hips to maintain center of mass over the feet, creating anterior rotation of the pelvic girdle. Extreme forward lean can lead to injury (Fry et al., 2003). Although these injuries could be just pain and nothing serious, it leads athletes to not perform to their best abilities. The pain can lead to detraining that causes athletes not to be able to compete at elite levels (Risch et al., 1993).

Justification

This literature review is important to understand the pressure and forces that are acting upon the lumbar spine with a forward lean. Adding load creates more compressive forces along the lumbar spine, and increasing the forward lean the lumbar spine endures more forces and pressure. Therefore, if the BSS can decrease forward lean, there would be less force on the lumbar spine and decreasing the chances of injury. After the review of literature, the reader will understand the effect forward leaning has on the lumbar spine.

Review of Literature

While performing a proper conventional squat the hips are displaced or push back before beginning the descent phase. While displacing the hips causes the pelvic girdle to anteriorly rotate which than leads to forward flexion of the hips and hyperextension of the spine. Just the simple change in the posture to begin the squat can cause low back pain (Evcik & Yücel, 2003). While squatting athletes that reject planar motion tend to have a more stable upright position (Schoenfeld, 2010). Those athletes reject the excessive forward lean and tend to keep their torso in a more upright position with the bar more over their hips.

Athletes can maintain an upright torso by looking up. In theory the torso follows what the eyes are doing, looking up keeps the torso up, looking down cause the torso to lean forward more. When looking up compared to down there is a difference of 4.5° of forward lean (Donnelly et al., 2006). If athletes are looking down, they are increasing their forward lean without knowledge of doing so. This simple gaze could be the difference between lumbar pain, deconditioning, and atrophy.

Gazing upward can help keep the torso in a more upright stable position is does not mean athletes are safe while squatting. By increasing the intensity or the load of the squat causes a linear rise of load on the vertebral bodies (Schoenfeld, 2010). Along with vertebral pressure the intradiscal pressure is increased as well (Cappozzo, Felici, & Figura, 1985)**.** This increase in vertebral and intradiscal pressure is just from the extra load that is sitting of the shoulders before the squat. While squatting that pressure will then increase because of the forward lean as stated above. The increase of forward lean increases the hyperextension of the lumbar spine. Simply increasing the load from 40% to 60% had a significant increase in the extension of the lumbar spine (Walsh, Quinian, Stapleton, Fitzpatrick, & McCormack, 2007)**.** The study also showed significant increases in extensions from increasing from 40% to 80% and from 60% to 80%. This shows that at lower weights athletes can keep the torso upright but increasing the load increases the forward lean and extension.

Possible alternatives to decrease the pressure and forces upon the spine are to use front squats. While performing the front squat the bar is right at the shoulders causing the torso to stay in a more upright position throughout the entire movement (Rippetoe, 2011). The torso being more upright leads to a decrease in forward lean significantly lowering compression or pressure on the lumbar spine compared to back squats.

The forces and pressure are greater on the spine and the hip joint when increase the load on the body. These forces and pressures increase while going through the complete movement of the squat. For the hips they have maximal torque near the bottom of the exercise (Schoenfeld, 2010). At the bottom of the squat the forces are almost the greatest, the forward lean has more significant impact on the forces and pressure. The degree of forward lean helps determine the forces and pressures acting upon the hip and the lumbar spine. The greater degree of forward lean put more force and pressure on the lumbar spine. The degree and forces act linearly with each other, as the forward lean increases the pressure increases (Race & Amis, 1994)**.**

While squatting the hips stay back and the torso tends to lean more forward while descending to the bottom of the squat. The forward lean can cause up to 30% more pressure on the lumbar spine than standing upright (Nachemson, 1965; Nachemson & Elfstrom, 1970)**.** With the increase of pressure on the lumbar spine can lead to injury. The little bit of pain experienced by the extra pressure can be increased with physical activity and the increase could lead to more severe injuries (Risch et al., 1993). To decrease the low back pain athletes are more likely to avoid physical activity. According to Risch et al. (1993) Avoiding physical activity will eventually lead to deconditioning which leads to atrophy.

While performing the squat coaches ask to increase the speed while the bar is being moved due to athletes need to be strong and fast. The squatting can be performed to a cadence so athletes understand how fast the bar should be moving. While this may result in increased bar speed and thus improvement in power, the compressive forces of the spine are double when the weight it being lifted rapidly (Vakos, Nitz, Threlkeld, Shapiro, & Horn, 1994). The faster speeds lead to joint related shearing and greater compressive forces at the spine and hip joints.

A difference from sitting with the torso in an upright position and sitting with a forward lean of the torso greater than approximately 20°, increases pressure along the lumbar spine (Nachemson & Elfstrom, 1970). The pressure along the lumbar spine was shown to increase by approximately 30%. These results show that a forward lean greater than 20° increases the pressure of the spine. While adding weight the subjects experienced an average increase of 120 kP at the 20° forward lean. Nachemson and Elfstrom showed those pressures increase by 160kP when the subjects increase to 30° of forward lean.

It has already been shown during the Review of Literature that the BSS puts up to 85% of the force on the front foot. Additionally, it decreases the lumbar load (Meyer, 2005)**.** These results were shown with a smaller barbell load but eliciting the same muscular effort. Other research demonstrated a greater load would increase the forward lean. The BSS requires less barbell load needed thus decreasing the forward lean. The BSS puts less force on the back but can produce greater EMG than the squat (DeForest et al., 2014). The BSS can produce greater results than the squat with less force of the lumbar spine, and less of a load while performing the exercise.

The review of literature has shown that most causes of lumbar pain while working out is simply from the body's anatomy while squatting. There are ways to prevent an excess of forward lean there will still always be forward lean that generates extra pressure and forces upon the lumbar spine. Increasing the load while squatting with just increase the forward lean that will increase the forces and pressure at the lumbar spine. Through Nachemson's (1970) study has given an idea that a forward lean greater than 20° is where the increase of pressure and forces comes from. The BSS suspects to keep the torso more upright hence the decrease of lumbar load, but can also produce greater EMG results compared to the conventional squat.

CHAPTER 3

METHODS

Introduction

This was an exploratory study to investigate the possible relationship between lumbar forward lean and force output during a BSS at higher and lower box heights. Research on the BSS, is scarce with no research using it for optimizing lower limb strength. Performance of the BSS has the rear leg elevated on a box, but it has been suggested that this can cause lumbar lordosis of the lower back, hindering athletes. With this, the purpose will be to determine if using a lower box height can produce similar outputs of force as a higher box without putting the lower back at risk of injury. To the authors knowledge this area has not been studied. Athletes were to complete a familiarization protocol approximately a month before testing took place. The testing took place during pre-season camp before the actual season begins, to minimize the effects of fatigue from training and conditioning.

Participants

Fifteen male Junior hockey players were recruited and completed testing protocol. Eleven participants completed testing. Two subjects were unable to complete the study due to injuries within three months prior to testing. Two other subjects did not complete the test due to illness on the day of testing. All athletes completed an informed consent stating they were taught how to properly perform a squat and could complete a correct squat on the day of testing. Each athlete is at least 18 years of age, and has no lower body injury in 3 months prior to testing, as provided in the informed consent. Assessments were taken place in Biomechanics Lab on the campus of the University of Northern Iowa. University IRB approval was attained prior to beginning the investigation.

Instrumentation

The athletes performed the test on a Force Plate (AMTI Force and Motion, Watertown, MA) in which they put their lead foot onto for calculating the maximal vertical force (200 Hz) incurred through the BSS. Maximum vertical force was recorded and documented for each repetition. The athlete was being recorded at a perpendicular angle, using a JVC high speed motion camera (60 FPS, JVC Kenwood USA, Long Beach, CA). Video analysis was used with MaxTaq (Innovision Systems, Columbiaville, MI) to generate an angle to determine a degree of forward lean.

Procedure

Athletes went through a familiarization protocol together prior to beginning the study. Data collection only occurred with the testing protocol. Testing was performed at University of Northern Iowa in the Biomechanics Laboratory. Athletes completed the testing procedure individually with box heights and elevated legs randomly assigned.

Prior to testing, athletes went through a warm up protocol of five minutes on an exercise bike at 70 RPM and dynamic movements, similar to their normal pre-training warm-up. Upon completion the bar was loaded to 30% of back squat 1RM (Meyer, 2005). 1RM was reported by the athletes during the informed consent. The athlete then began the testing procedure. The testing procedure was 12 total repetitions. Starting with three repetitions of one foot forward at either a box height of 40 cm or 20cm. Athletes were instructed to place their lead leg on a force plate while the rear leg was on a set box height of 20 or 40 cm from the force plate. Athletes were given a one-minute rest period between each set. Athletes then switched legs and followed the same protocol. This protocol was followed until all twelve repetitions were completed. The entire test including warm up took approximately 15-20 minutes per person.

Digital video analysis was exported onto a computer and converted to AVI. AVIs were opened in MaxTaq computer software to generate forward lean angles. The torso was visually divided into equal anterior and posterior halves. The quadricep was then visually divided into equal superior and inferior halves. The point where the two met estimated the center of the hip joint. The angle was generated from the visually estimated hip joint and the equal division of the torso. The angle was originally reported as a horizontal angle, thus the inverse was used to determine the vertical angle or the forward lean. All angles were exported into Microsoft Excel (Microsoft Inc, Redmond, WA) to create a PivotTable for comparisons between the high and low boxes forward leans.

Statistical Analysis

Means and standard deviations were computed to describe several characteristics of the participants. (Table 1). A MANOVA to determine was used to test differences in force forward lean between 20 cm and 40 cm the of 40 cm and 20 cm. Paired t-tests were computed as Post HOC to determine where the differences were. Paired followed up significant MANOVA results when appropriate. A paired T-test was used to compare the differences in force between the high and low box conditions. A separate paired t-test was used to compare the differences in forward lean between the high and low box conditions. Significance was set at $p < 0.05$ across all statistical computations. Cohen's *d* effect size was calculated to determine for the force and forward lean between both box heights conditions ($p < 0.05$). All statistics were completed using SPSS version 22 (IBM Analytics, Armonk, NY)

CHAPTER 4

RESULTS

The athletes were 18.55±0.69 years, 180.73±6.66 cm, and 80.45±7.63 kg. The barbell load was 30% of the athletes reported back squat 1RM. The barbell load was 60.95±12.36 kg. Detailed statistical information of participants can be found in Table 1.

Table 1.
Descriptive Statistics of Participants.

ID	Height(cm)	Weight(kg)	Age	30% 1RM(kg)	Load Including Bar(kg)
1	170	67	18	18.18	38.64
3	188	85	18	52.27	72.73
4	180	85	19	43.18	63.64
5	173	76	18	27.27	47.73
6	178	80	19	38.64	59.09
8	185	83	19	47.73	68.18
9	178	71	19	38.64	59.09
10	175	76	18	34.09	54.55
11	187	90	18	56.82	77.27
13	191	92	18	56.82	77.27
14	183	80	20	31.82	52.27
Mean	180.73	80.45	18.55	40.50	60.95
SD	6.66	7.63	0.69	12.36	12.36

All data is reported for the lowest point of the lift, defined as the moment before the athletes began ascending to the starting position. The low point was determined by the athlete, as they were instructed to descend as low as possible.

Multivariate rejected the omnibus null hypothesis (F (2,9) = 92.5, p<0.01). Individual paired sample t-tests, the box height of 40 cm resulted in significantly greater force than the box height of 20 cm (t_{10} = 3.8, p = 0.03, Cohen's *d* = .21). Similarly, the box height of 40 cm condition resulted in significantly greater forward lean (t_{10} = 13.24, p < 0.01, Cohen's *d* = 5.22). Means and standard deviations are available in Table 2.

Table 2.

Means (SD) of force and forward lean between high and low box conditions (N = 11)

	40 cm	20 cm
Force (N)	1163.15± 194.44	1121.86± 197.11
Lean (°)	27.56± 1.86	19.39± 1.21

CHAPTER 5

DISCUSSION

This study sought to determine the differences between two box heights on force and forward lean in the BSS. It was observed that at a box height of 40 cm generates a significantly greater force output compare to that of a 20-cm box. Furthermore, at box height of 20 cm results in significantly less degrees of forward lean compared to a box height of 40 cm.

The BSS should be used in all strength and conditioning protocol, due to producing 85% force per leg (Speirs, Bennett, Finn, & Turner, 2015). Using the lower box height of 20 cm produce practically the same force as 40 cm box height but has significantly less forward lean, making 20 cm the better option to use. The BSS can be used in addition with the squat to focus more each leg, but can also take the place of the squat in rehabilitation instances.

The significance difference means that elevating the foot higher does generate higher force outputs but also increases the forward lean. As stated earlier, the greater forward lean leads to more force upon the spine. Though pressure or forces acting upon the lumbar spine were not calculated it is speculated that the 40-cm box elicits higher forces on the lumbar spine. This is important to understand as coaches planning to incorporate the BSS into their programing. For training consideration, even though a greater force is on the foot there is greater force on the spine. As the leg could potentially be getting bigger and stronger, the lumbar spine is experiencing greater force which could be counterintuitive.

Though it was shown that there is statistically significant difference in the force output there is not practical difference. The difference of 42 N speculates the difference of such small degree of force is due to the forward lean. As the athletes lean more forward the bar weight is shifted forward positioning the weight over the foot. Thus, when measuring the vertical force can lead to higher force outputs. With the lower box heights, the friction forces are likely greater, which generates less vertical force. However, the sum of the total forces would likely be the same, although differences were shown they forces may be equal. This ideal is not proven it is only speculated by the author.

With a linear increase of the load and the compression of the spine (Schoenfeld, 2010) it is speculated that greater than 30% of the 1RM would generate more forward lean. Based off what has been shown in the literature reviews and this study, it is possible that it could potentially cause greater forces. While performing the exercise of a box height of 40 cm, the forces could potentially be too great, and would increase the likelihood of injury in an athlete. While performing on the 20 cm, could generate a greater force on the front foot but still have lower forces on the lumbar spine protecting the athlete. This ideal of an optimal height and intensity would need to be investigate and performed before it can be confirmed.

Practical Application

When considering programming the BSS into the annual plan strength and conditioning coaches need to question what they want for results. All coaches should use box heights of 20 cm due to practically insignificant forces and significant difference in forward lean. Using the 20-cm box height can produce 85% force on each leg resulting in both strength and hypertrophy while putting less stress on the lumbar spine. Strength and conditioning coaches need to understand that increasing the forward lean increases the pressure on the lumbar spine (Race & Amis, 1994) and choose if that is worth it for the small increase in force on the forward leg.

The studies main limitation is the division of the torso is objectified by the person digitizing, thus creating a flaw within the study. This study should be replicated using 3D motion analysis to accurately judge the degree of forward lean.

REFERENCES

Ardison, Staci. (2017). *Strength Training101: How to Squat Properly.* Retrieved July 3, 2017, from https://www.nerdfitness.com/blog/strength-training-101-how-to-squat-properly/

Asmussen, E., & Heeboll, K. (1961). Isometric Muscle Strength in Relation to Age in Men and Women. *Ergonomics*, 167-169.

Baechle, R., & Earle, R. (2000) *Essentials of Strength Training and Conditioning* (2nd ed.). Champaign, IL: Human Kinetics, 2000

Bobbert, M. F., Graaf, W. W. de, Jonk, J. N., & Casius, L. J. R. (2006). Explanation of the bilateral deficit in human vertical squat jumping. *Journal of Applied Physiology*, *100*(2), 493–499. https://doi.org/10.1152/japplphysiol.00637.2005

Boyle, K. (2015, December 16). *Step by Step Guide on how to Do a Bulgarian Split Squat*. Retrieved from Lifting Revolution: http://www.liftingrevolution.com/step-by-step-guide-on-how-to-do-a-bulgarian-squat/

Cappozzo, A., Felici, F., & Figura, F. (1985). Lumbar Spine Loading During Half-Squat Exercises. *Medicine and Science in Sports and Exercise* , 613-620.

Chang, C., Chang, C., Lin, K.C., & Ho, C.S. (2016). Effect of DIfferent Tibia Angles to Loading of Knee During Split Squat. *34th International Conference on Biomechanics in Sports*, 251-253.

DeForest, B. A., Cantrell, G. S., & Schilling, B. K. (2014). Muscle Activity in Single- vs. Double-Leg Squats. *International Journal of Exercise Science*, *7*(4), 302–310. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/27182408%5Cnhttp://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=PMC4831851

Donnelly, D., Berg, W., & Fiske, D. (2006). The Effect of the Direction of Gaze on Kinematics of the Squat Exercise. *Journal of Strength and Conditioning Research*, (September), 145–150. https://doi.org/10.1519/R-16434.1

Evcik, D., & Yücel, A. (2003). Lumbar lordosis in acute and chronic low back pain patients. *Rheumatology International*, *23*(4), 163–165. https://doi.org/10.1007/s00296-002-0268-x

Fry, A. C., Smith, J. C., & Schilling, B. K. (2003). Effect of knee position on hip and knee torques during the barbell squat. *Journal of Strength and Conditioning Research / National Strength & Conditioning Association*, *17*(4), 629–633. https://doi.org/10.1519/1533-4287(2003)017<0629:EOKPOH>2.0.CO;2

Goss, K. (2013). T*he Truth about the Bulgarian Split Squat*. Retrieved July 3, 2017, from http://main.poliquingroup.com/ArticlesMultimedia/Articles/Article/1062/The_Truth_About_the_Bulgarian_Lunge.aspx

Hamill, J., & Knutzen, K. (2008). *Biomechanical Basis of Human Movement.* LWW, Philadelphia, PA.

Jones, M. T., Ambegaonkar, J. P., Nindl, B. C., & Smith, J. A. (2012). Effects of unilateral and bilateral lower-body heavy resistance exercise on muscle activity and testosterone responses. *The Journal of Strength and Conditioning Research*, *26*(4), 1094–1100. https://doi.org/10.1519/JSC.0b013e318248ab3b

McCurdy, K., Langford, G. A., Doscher, M. W., Wiley, L. P., & Mallard, K. G. (2005). The effects of short-term unilateral and bilateral lower-body resistance training on measures of strength and power. *Journal of Strength and Conditioning Research*, *19*(1), 9–15. https://doi.org/10.1519/14173.1

McCurdy, K., O'Kelley, E., Kutz, M., Langford, G., Ernest, J., & Torres, M. (2010). Comparison of lower extremity EMG between the 2-leg squat and modified single-leg squat in female athletes. *Journal of Sport Rehabilitation*, *19*(1), 57–70. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/20231745

Meyer, B. W. (2005). *A comparison of hip and knee extension torques in conventional and split squat exercises* (unpublished master's thesis). Indiana University, Bloomington, IN.

Nachemson, A. (1965, May). The Effect of Forward Leaning on Lumbar Intradiscal Pressure. *Acta Orthopaedica Scandinavica*, *35*, 314–328. https://doi.org/10.3109/17453676508989362

Nachemson, A., & Elfstrom, G. (1970). *Intravital dynamic pressure measurements in lumbar discs.pdf.* Stockholm, Sweden: Almqvist and Wiksell.

Negrete, R., & Brophy, J. (2000). The relationship between isokinetic open and closed chain lower extremity strength and functional performance. *The Journal of Sport Rehabilitation*, *9*(1), 46–61. https://doi.org/10.1123/jsr.9.1.46

Race, A., & Amis, A. (1994). The Mechanical Properties of the Two Bundles of the Human Posterior Crucialte Ligament. *Journal of Biomechanics*, 13-24.

Rippetoe, M. (2011). *Starting Strength Basic Barbell Training.* The Aasgaard Company, Wichita Falls, Texas.

Risch, S. V, Norvell, N. K., Pollock, M. L., Risch, E. D., Langer, H., Fulton, M., … Leggett, S. H. (1993). Lumbar strengthening in chronic low back pain patients. Physiologic and psychological benefits. *Spine*. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/8185727

Schantz, P. G., Moritani, T., Karlson, E., Johansson, E., & Lundh, A. (1989). Maximal voluntary force of bilateral and unilateral leg extension. *Acta Physiologica Scandinavica*, *136*(2), 185–192. https://doi.org/10.1111/j.1748-1716.1989.tb08651.x

Schoenfeld, B. S. (2010). Squatting Kinematics and Kinetics and Their Application to Exercise Performance. *Strength and Conditioning Research*, *24*(12), 3497–3506.

Soest, A. J. Van, Roebroeck, M. E., Bobbert, M. F., Huijing, P. A., & Schenau, G. J. V. I. (1985). A comparison of one-legged and two-legged countermovement jumps. *Medicine and Science in Sports and Exercise*. https://doi.org/10.1249/00005768-198512000-00002

Speirs, D. E., Bennett, M., Finn, C. V., & Turner, A. P. (2015). Unilateral vs Bilateral Squat training for Strength, Sprints and Agility in Academy Rugby Players. *Journal of Strength and Conditioning Research*, 1–28. https://doi.org/10.1519/JSC.0000000000001096

Vakos, J., Nitz, A., Threlkeld, A., Shapiro, R., & Horn, T. (1994). *Electromyographic Activity of Selected Trunk and Hip Muscles During a Squat Lift* (Unpublished master's thesis). University of Kentucky, Lexington, KY.

Vertical force (Fz). (2009). *llustrated Dictionary of Podiatry and Foot Science* by Jean Mooney. https://medical-dictionary.thefreedictionary.com/vertical+force+(Fz)

Walsh, J., Quinian, J. F., Stapleton, R., Fitzpatrick, D., & McCormack, D. (2007). Three-Dimensional Motion Analysis of the Lumbar Spine During "Free Squat" Weight Lift Training . *The American Journal of Sports Medicine*, 927-932.

Whiting, W., & Rugg, S. (2015). *Dynatomy Dynamic Human Anatomy.* Champaign, IL: Human Kinetics.

Wilson, G.J., Murphy A.J., & Giorgi A. (1996). Weight and plyometric training: Effects on eccentric and concentric force production. *Can. J. Appl. Physiol. 21,*301–315.