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Lower Body Kinematic Comparisons between Front and Back Squats in Response to Loads

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LOWER BODY KINEMATIC COMPARISONS BETWEEN FRONT AND BACK SQUATS IN RESPONSE TO LOADS

A Thesis Presented

By

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LOWER BODY KINEMATIC COMPASISONS BETWEEN FRONT AND BACK

SQUATS

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ABSTRACT

Title of Thesis: **LOWER BODY KINEMATIC COMPARISONS BETWEEN FRONT AND BACK SQUATS IN RESPONSE TO LOADS**

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The squat is considered as one of the most popular exercises prescribed by therapists, athletic trainers, researchers, coaches, and athletes for injury prevention and strength and conditioning. People commonly associate the squat exercise as the back squat. However, the front squat has been advocated to reduce the stress to the lower back while increasing the leg strength. The proper front squat technique and the changes in the spine and lower extremity joints in response to load mass are still unclear. Therefore, the purpose of this study was to examine the lower body kinematic comparisons between front and back squat exercises in response to loads. Eight experienced varsity male lifters (age 20 ± 0.8 years) participated in this study. Each participant performed four trials of back and front squat exercises at three different loads (65%, 75%, and 85% of 1 repetition maximum). A standard two-dimensional kinematic analysis was conducted, and video trials were captured at 60 Hz. A two-way (2 types of squat x 3 different loads) repeated measures ANOVA was conducted at $\alpha = 0.05$ and followed up by Bonferroni adjustment if a significant difference was found. The result showed that there was a statistically significant diffrence in the knee flexion, trunk inclination, and angluar velocity of spine between both squat execises. Therefore, this study provides a crucial understanding about the front and back squat movements in response to different loads and suggests the importance of prescribing strengthening exercise targeting the knee joint in the front squat and the trunk stability in the back squat.

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The squat is a basic and popular resistance training exercise for core muscle strength development. The squat became a popular choice of free weight exercises when lifters began using dumbbells and barbells. A German wrestler and lifter, Henry Steinborn was believed to be the first person to introduce the squat exercise into an athletic training program. Steinborn found other resistance training exercises had greatly increased their popularity after he incorporated the squat exercise, particularly the Olympic lifting exercises (Dumitrache, 2010). The motion of squatting is the same as the first phase of the Olympic lifting exercises such as the snatch and clean. In the 1960s, scientific evidence reported that the movements of squatting could potentially lead to knee injury (Chandler, Mcmillan, Kibler, & Richards, 2000). Since the 1960s, through research studies conducted on athletes, animals and individuals who have been through injury rehabilitation, many practitioners have believed that squatting exercises are safe to perform when performed properly. In addition, it was reported that the half squat with an external load was safe to use for quadriceps strengthening (Sahli, Rebai, Elleuch, Tabka, & Poumarat, 2008). Poor technique and loss of form may be the most common cause of injury in squatting, particularly when heavy weights are lifted (Walsh, Quinlan, Stapleton, FitzPatrick, & McCormack, 2007). Squat exercises became increasingly popular in clinical settings as means to strengthen lower body muscles and connective tissue after joint-related injuries (Schoenfeld, 2010). As a result, coaches and athletic trainers believe that squat exercises may help athletes reduce injuries and increase performance.

The squat is a resistance training exercise that involves lowering a load such as barbells toward the ground by flexing both hip and knee joints. The movements of the squat can be observed in daily tasks such as lifting and picking up a box. The squat has different techniques including the back squat, front squat, hack squat, and overhead squat. Among these squat exercises, back and front squats are the most frequently used squats by athletes and the general population. The front squat is a variation of the squat, which strengthens core muscles while maintaining a proper back posture with a load mass that is positioned on the anterior portion of the shoulder region on top of the clavicle bones and deltoid muscles. The back squat is a variation of the squat with a load mass that is positioned on the posterior portion of the upper body at the base of the neck and on top of the trapezius. The movement of both squats begins in a standing position and then hip and knee joints flex to lower the resistance load (Figure 1).

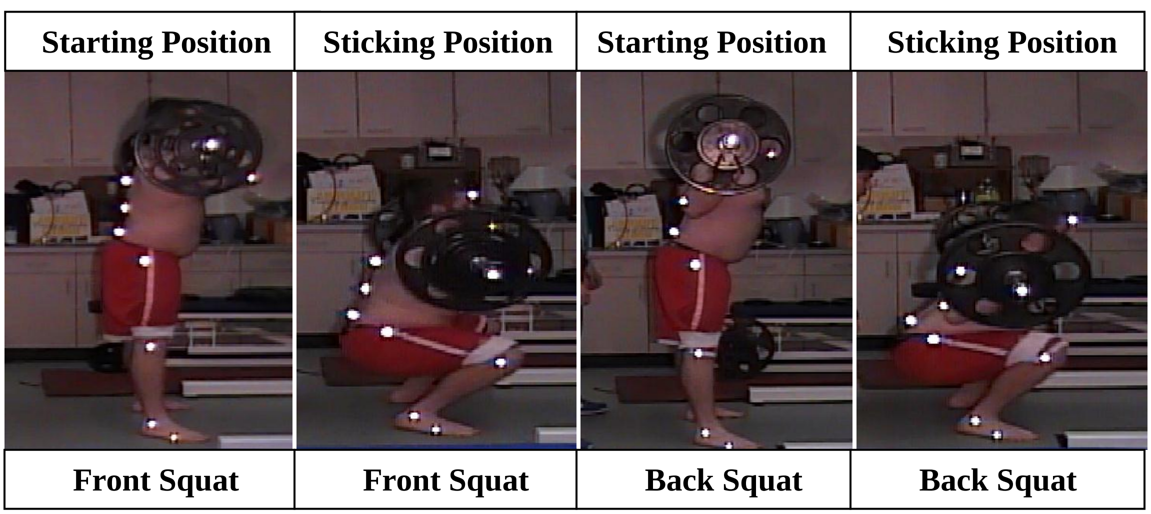

Figure 1. Standing and sticking positions of front and back squat exercises.

Performing squat exercises can increase leg strength because squats recruit multiple muscle groups such as quadriceps muscles, hip extensors, hip adductors, hip abductors, and the triceps surae in a single maneuver. However, performing squat exercises with improper technique may potentially cause joint-related injuries in the spine and lower extremities including the hip, knee, and ankle due to the amount of force from the load mass. When performed properly, squat related injuries are uncommon. However, if the mechanics of the squat are not properly executed, the documented injuries from squatting may include muscle and ligament sprains, ruptured interverebral discs, spondylolysis, and spondylolisthesis (Vakos, Nitz, Threlkeld, Shapiro, & Horn, 1994). The spine is a very intricate column composed of vertebrae, intervertebral discs, nerves, and the spinal cord. The spine extends from the skull to the pelvis and is made up of 33 individual vertebrae that are separated by the intervertebral discs, which act as shock absorbers. The spine's vertebrae are divided into five sections from the neck to the tailbone: cervical, thoracic, lumbar, sacrum, and coccyx. A research study estimated that 10-15% of all sporting injuries involve the spine and of the five sections, the lumbar region is by far the most prone to injury (Durall & Manske, 2005). It has been estimated that up to 80% of adults will eventually develop some form of low back pain (Durall & Manske, 2005). Because of this, the squat exercise which puts heavy stress on the spinal joints has to be performed with extensive care and caution. Some therapists, athletic trainers, and coaches believed that the front squat exercise could be more beneficial to athletes than the back squat because the front squat may put less stress on the lumbar spine than the back squat due to its less posterior inclination position of the trunk. Moreover, the front squat load position requires more knee flexion compared to the back squat. Additionally, during the front squat exercise the athlete's trunk angle better represents the acceleration phase of a sprint start, which follows the training principle of sport specificity. Howerver, the changes in the spine and lower extremity joints in response to load mass remain to be determined. Therefore, the purpose of this study is to examine the lumbar spine, hip and knee during the front and back squat exercises in response to diffrent load masses. The findings could help coaches and practitioners provide better squatting exercise instruction to reduce the lumbar spine, hip and knee injury risk.

Purpose

The purpose of this study was to compare the kinematics of the lumbar spine, hip and knee for the front and back squat exercises in response to loads. Specifically, the kinematic variables of joint angle and joint velocity of the lumbar spine and the hip and knee joints for both front and back squats were examined in response to load masses of 65%, 75% and 85% of a 1 repetition maximum. By comparing both front and back squat exercises, researchers were able to obtain a comprehensive understanding about the movement of the squat exercise and the effects of different load masses on joint motions.

Statement of Problem

The squat is a resistance training exercise that is capable of strengthening multiple major muscle groups in a single movement. The back squat is a more popular squatting exercise than the front squat. The two squat techniques are different in terms of bar placement locations. The barbell position of the back squat is on the trapezius muscle that is above the posterior area of the deltoids. However, the barbell placement of the front squat is on the anterior deltoid muscles and clavicle bones, and the position of the upper arms is parallel to the ground. Practitioners and coaches believe that the front squat is safer than the back squat to perform due to its place of the barbell on the body, and they also believe that the front squat exercise may prevent lumbar curvature from becoming hyperlordosis. However, there is a lack of research that has examined the changes of the spine motion between front and back squat exercises. Additionally, some coaches believe that a greater posterior trunk inclination angle of the front squat exercise increases hip flexion. Thus, it increases the forward trunk lean angle during the squat, so it better represents a sprint start, which enables athletes to improve their running speed based on the principle of sport specificity training. However, the question of how much is the posterior trunk inclination angle in the front squat exercise when compared to the back squat exercise has not yet been quantified and documented. Therefore, the kinematic analysis of the posterior trunk inclination angle during both squats needed to be evaluated, so the practitioners and the coaches could acquire a comprehensive understanding about both squat exercises.

Further, when squatting exercises are prescribed to develop strength and power, lifters gradually increase the load mass based on the percentage of their one repetition maximum (1RM). However, as the load mass increases, the effects of load mass on the lumbar spine and lower body joints are unknown. Due to the lack of empirical evidence, the research on kinematic comparisons between the front squat and back squat with increasing load masses needed to be examined, so therapists and coaches could acquire a better understanding about the squat exercise, which would help to provide safer instruction to their patients and athletes.

Hypotheses

This research investigated the kinematic differences between the front squat and the back squat. This study examined the differences of the lumbar spine, the hip and knee between both squats for enhancing squat performance or preventing lifting injuries. It was hypothesized that the statistically significant difference of the lumbar spine, hip, and knee joint angle between front squat and back squat was found when the load mass was increased. Gullett, Tillman, Gutierrez, and Chow (2009) reported that the compressive forces and extensor moments increased in the back squat more than in the front squat. In addition, the mean maximum lumbar shear force during the front squat (69.13% of system mass; 143% of body weight) was reported to be larger than the back squat (67.34% of system mass; 139% of body weight) (Russell & Phillips, 1989). Although mean maximum lumbar shear forces between the two squats were found to be similar and no statistical significant difference, Russell and Phillips believed that the stress of the load mass on the spine and lower body joints could affect the kinematics. Therefore, the researcher hypothesized that there was statistically significant difference between back and front squats at the lumbar spine, hip, and knee. The researcher anticipated that the lumbar spine angle for the front squat was higher than the back squat, and the knee joint angle was greater for the back squat, and more prominent when the load mass was increased.

Limitations

- This study assumed that participants provided their maximum effort during the testing.
- The psychological factors were not controlled in the study.

Delimitations

- Lifters with at least 5 years experience in lifting were examined. It was necessary to assume that experienced lifters are more reliable than novice lifters because experienced lifters have a better understanding of the squat exercise. Thus, the errors in performing the squat were minimized.

- Ages of participants were limited from 18 to 25 years old with free of injury in the past two years.

- Participants performed the deep squat instead of the parallel squat.

- The percentage load mass of each subject's one repetition maximum was used instead of percentage load mass of the subject's body weight.

- Only male lifters participated in this study due to the kinematic and kinetic difference between male and female lifters. A female's center of gravity is lower and more close to the spine. Additionally, a female's pelvis is wider than a male pelvis, which means a female's femur bone approaches the knee at a wider angle known as the "Q" Angle.

- This study tested 65%, 75%, and 85% of 1RM load mass.

- Participants performed each squat exercise for four repetitions.

Significance of the study

Understanding the kinematics of the squat is very important in the field of athletic training. The squat exercise puts stress on the spinal joints, and it is documented that lifting injuries are most frequently related to low back pain (Hsiang, Brogmus, & Courtney, 1997). A research study examined the effects of the load on the spine during squat exercises, and the study found that lumbar curvature was adjusted from kyphosis to the lordosis in the squat lifting without regard to weights, and the lumbar moment was increased with increased load masses (Hwang, Kim, & Kim, 2009). As load masses were increased, spine muscular activity was increased as well. However, the squat exercise is one of the most popular prescribed exercises for athletes and injury-rehabilitation communities because it enables lower body muscular strength development. Hence, the controversy exists with regard to the safety and benefits of squats. Nevertheless, with improper squat lifting technique, either front or back squat exercises may potentially cause joint-related injuries in the spine and lower extremities. Thus, kinematic analysis of the spine and lower extremities between back and front squats needed to be examined. Therefore, the results of this study would contribute to the base of knowledge on squatting mechanics by providing kinematic information on the movement of the lumbar spine, hip, and knee in response to different load masses. The findings would allow athletic trainers and athletes to choose an appropriate squat exercise based on the individual's needs. If there was no significant difference found in this study, therapists, athletic trainers, and coaches could prescribe the front squat and back squat interchangeably. However, if a significant difference was found, therapists, athletic trainers, and coaches would need to consider the type of squat exercises and percentage of one repetition maximum load mass in their program prescription carefully.

LITERATURE REVIEW

Introduction

The squat exercise is increasingly popular in clinical settings as a means to strengthen lower-body muscles and connective tissue after joint-related injuries (Fry, Smith, & Schilling, 2003; Kritz, Cronin, & Hume, 2009; Rippetoe, 2001; Schoenfeld, 2010). As a result, coaches and athletic trainers believe that squatting exercise may help athletes reduce injuries and increase performance. The squat is believed to reduce the stress to the lower back while increasing leg strength, and it also recruits multiple muscle groups in a single maneuver, including the quadriceps femoris, hip extensors, hip adductors, hip abductors, and triceps surae. However, performing a squat exercise with improper technique may potentially cause joint-related injuries in lower extremities including the spine, knees, and ankles due to the amount of forces from the mass of the barbell that is placed on the joints. When performed properly, squat–related injuries are uncommon. However, documented injuries from squatting include muscle and ligament sprains, ruptured interverebral discs, spondylolysis, and spondylolisthesis (Vakos et al., 1994). The spine is a very intricate column composed of vertebrae, intervertebral discs, nerves, and the spinal cord. The spine extends from the skull to the pelvis and is made up of 33 individual vertebrae that are separated by the intervertebral discs, which act as shock absorbers. The spine vertebrae are divided into five sections from the neck to the tailbone: cervical, thoracic, lumbar, sacrum, and coccyx. Of the five sections dividing the spine, the lumbar region is by far the most prone to injury. It has been estimated that up to 80% of adults will eventually develop some form of low back pain (Durall & Manske, 2005). Additionally, it has been estimated that 10-15% of all sporting injuries involve the spine (Durall & Manske, 2005). Because of this, the squat exercise which puts heavy stress on the spinal joints has to be performed with extensive care and caution. Some therapists, athletic trainers, and coaches believe that front squat exercise may be more beneficial to the athletes than the back squat because the front squat exercise enables athletes to have greater amounts of flexion in the knee and ankle joints. Additionally, the front squat may put less stress on the lumbar spine than the back squat due to its greater posterior inclination angle, which also better represents the acceleration phase of a sprint start. However, the changes in the lumbar spine, hip, knee and trunk in response to load mass for both squats remained to be determined.

Squat technique

Proper squat technique may serve as a foundation for the prevention of musculoskeletal system injuries and overloads. Proper behavior of joints acts as a key to optimize the squat performance (Czaprowski, Biernat, & Kedra, 2012). To obtain proper squatting technique, the foot width, unrestricted ankle, knee range of motion, and the direction of gaze (head direction) are important. It has been previously recommended that using a wide foot stance (same or wider than shoulder width) will minimize the risk of injury and retain maximum activation of the leg muscles (Comfort & Kasim, 2007). The research study conducted by Almosnino, Kingston, and Graham (2013) indicated that the wide stance allows the athlete to have less internal rotation and adduction moment at the knee when compared to the parallel stance. The purpose of their study was to investigate the effects of stance width and foot rotation angle on three-dimensional knee joint moments during the bodyweight squat exercise. The number of subjects were twentyeight (17 males and 11 females) and they performed eight repetitions in four conditions (1. shoulder width parallel 2. shoulder width rotated 3. wide stance parallel 4. Wide stance rotated). The results of their research study showed that a greater knee flexion moment was observed as the stance width was increased, and the external rotation of the knee on the wide stance width resulted in reducing the knee's internal rotation moment (Almosnino et al., 2013). Another research study showed that restricted ankle dorsiflexion during the squat could lead to a decrease in peak knee-flexion angle, which could increase soleus and decrease quadriceps muscle activities (Macrum, Bell, Boling, Lewek, & Padua, 2012). The purpose of this study was to examine the effect of restricted ankle dorsiflexion range of motion on kinematic and electromyographic activity during a squat. This research study hypothesized that limited range of motion could change knee kinematics and lower extremity electromyography activity. Thirty participants free of lower extremity injury (15 males and 15 females) participated. The authors conducted a three-dimensional analysis on hip and knee kinematics with seven infrared video cameras. Two conditions were the non-wedge condition (foot flat on the ground) and wedge condition (12 degree of forefoot angle). This research study reported that knee flexion decreased while ankle dorsiflexion and knee valgus increased on the wedge condition. Ankle dorsiflexion increased by 9.5° with the wedge condition in comparison with the non-wedge condition. Peak kinematic variables indicated that knee flexion decreased while knee valgus and dorsiflexion increased. Displacement values showed that knee flexion and ankle dorsiflexion decreased on the wedge condition while medial knee displacement increased. Electromyography activity of the soleus increased. However, electromyography activities of the vastus lateralis and the vastus medialis oblique decreased, which implies that the restriction of ankle range of motion could have an effect on muscle activation at the knee (Macrum et al., 2012). Thus, maintaining a dorsiflexion angle of 38.5 ± 5.9° was necessary to keep the heels down during the squat (Schoenfeld, 2010). Furthermore, the downward gaze during the squatting motion was shown to increase hip flexion and trunk flexion, so it is important to keep the head or direction of gaze below a neutral position. The research study was conducted to examine the influence of the direction of gaze on the kinematics of the squat exercise (Macrum et al., 2012). Ten male subjects participated with conditions of downward gaze, straight gaze, and upward gaze. Each participant performed two sets of five reps of 25% of their one repetition maximum in each of three different conditions. This research study found that the mean maximum trunk, hip, and knee flexion were greatest when the direction of gaze was directed downward, and the hip flexion was greater while using the downward gaze than the upward gaze. The result also showed a tendency of trunk flexion to be more severe in the downward gaze. However, knee flexion was not affected by gaze direction (Donnelly, Berg, & Fiske, 2006). Based on the findings of epidemiology of weight training-related injuries in the United States from 1990 to 2007, a total of 25,335 weight training injuries were seen in United States Emergency Department that correlated to an estimated 970,801 injuries nationwide (National estimates were computed by utilizing statistical weights provided by the US Consumer Product Safety Commission's National Electronic Injury Surveillance System to actual counts). The lower extremity (19.7%) and upper extremity (25.3 %) were the most commonly injured body parts. Along with this number, sprain and strain (46.1%) were the most common diagnosis (Kerr, Collins, & Comstock, 2010). Because of this reason and with squatting being one of most common exercises, having a better understanding of the proper technique allows us to prevent the risk of injuries during the squat.

The squat is frequently used in rehabilitation and strength and conditioning areas because the squat exercise is relatively easy for both the general population and athletes to learn and has a positive impact on functional developer of the body. One of the reasons why the squat is a very popular exercise is because the rates of injuries are among the lowest in comparison with all other sports and related activity. An Olympic lifting exercise such as the clean is similar to the athletic power position. The clean exercise begins with maximum hip and knee flexion that is similar to the front squat exercise (Chiu, 2007). The stance of squat is called 'closed chain exercise' and reduces strain on the knee ligaments such as anterior cruciate ligament (Signorile, Weber, Roll, Caruso, Lowensteryn, & Perry, 1994). The risk of injury in the squat exercise is lower than the leg extension exercise because the center of gravity of the load can be held close to the body (Comfort & Kasim, 2007). Therefore, the squat minimizes the spinal bending moment and compressive forces on the back. The front squat was found to produce significantly lower maximal joint compressive forces at the knee as well as reduced lumbar stress as compared with back squats. Front squats may be a better alternative than back squats for those with ligament or meniscal injuries (Gullett et al., 2009). Generally, the squat exercise can be an effective rehabilitation tool (Escamilla, 2001).

Performing squat exercises at a low intensity (30% or 50% of 1RM) may be used to develop power rather than muscular strength because maximal strength training is only half of the equation (power=force*velocity). The squat has power outputs lower than clean and jerk exercises. The squat exercise requires qualities that need to be trained and enhanced (Chiu, 2007). The greater amount of trunk inclination angle of the back squat exercise may increase the risk of low back injury.

A spine change during the squat

The motion of spine includes two regions, the neutral zone and the elastic zone. In the neutral zone, lumbar rotation could occur with little resistance. In contrast, the elastic zone that ligaments, facet joints and intervertebral disks are attached to resist the lumbar rotation. Greater amount of mass loads influence these structures when it moves out of a functional neutral range (Maduri, Pearson, & Wilson, 2008). A half-squat with a barbell load between 0.8 to 1.6 times bodyweight produced compressive forces on the L3-L4 segment equating to 6 to 10 times bodyweight (Cappozzo, Felici, Figura, & Cazzani, 1985). In weight lifting, there is a chance of having a spinal injury (Aggrawal, Kaur, Kumar, & Mathur, 1979). The spine is particularly vulnerable to the effects of fatigue. Failure of the vertebral body occurs at much lower forces when subjected to fatigue (Vakos et al., 1994). As a person moves, a range of lumbar curvatures is available for any torso inclination. Maduri et al. (2008) examined the range of lumbar curvature rotation for the four inclination angles (0, 30, 60, and 90 degrees during lifting tasks (heavy slow, heavy fast, light slow, and light-fast) with 0.9 kg milk crate. Eleven male and female participants (4 females and 7 males) were examined in this study. They reported that the maximum and minimum lumbar curvature altered from lordotic in an upright trunk posture to kyphotic in a flexed trunk posture (Maduri et al., 2008). Flexion of the trunk is a risk factor for low back pain because back pain may occur due to spinal compression (Punnett, Fine, Keyserling, Herrin, & Chaffin, 1991). The peak extensor moment was reduced by about 10% when performing stoop lifting in comparison with squat lifting, but the bending torque was increased by about 75%. Both the extensor moment of the erector spinae muscles and the bending torque on the lumbar spine showed great increases with increasing mass (Dolan, Earley, & Adams, 1994). The lumbar vertebral bodies and intervertebral discs resist approximately 80% of the compressive force acting on the spine in the upright standing posture, with about 40% of the vertebral body's resistance being supplied by the cortical shell. The vertebral body is the first spinal structure to fail during compression, and its ability to resist this force depends on the age, sex, and body mass of the individual, along with the subject's bone mineral density (Adams & Dolan, 1995). Performing the squat requires stability of the spine in order to maintain the squat posture. A significant amount of lumbar hyperextension was observed at the load of 60% and 80% of the maximum weight lifting capability (28 males: 60% = 63.75 kg, 80% = 85.41 kg / 20 females: 60% = 43.13 kg, 80% = 58.7 kg) in this study, which is a cause for concern among the adult athletic population, particular for skeletally immature athletes (Walsh et al., 2007). Hwang et al. (2009) reported that the hip and the ankle led to the most parts of the support moment (summation of all lower extremity joint moments: ankle, knee, hip, and lumbar joints) during squat lifting. This research examined kinematics and kinetics of the lower body and lumbar lordosis using three-dimensional analysis. Twenty-six males participated and load masses were five, ten, and fifteen kilogram. They used a Vicon plug in with forty-three reflective markers placed on the participant's body. They concluded that the hip and ankle made for the most parts of the support moment during squat lifting and the hip, ankle, and lumbar joints generated power (concentric). This research study also showed only the knee joint absorbed power (eccentric) in the squat lifting. Significant correlations were found among all three lower extremity joint moments with the lumbar joint at the time of lordotic curvature appearance in the squat lifting. The lumbar curvature was changed from the kyphsis to the lordosis at about 50% of the range of motion (ROM) in the squat lifting regardless of weights (Hwang et al., 2009). However, this study used three weights that are five, ten, and fifteen kg. When load mass increases, the spine may get more stress and compression, which may affect the posture including the spinal angle. Thus, it is important to evaluate spinal joint movement because practitioners and coaches believe that anterior inclination of the front squat may put heavy stress on the spine.

Comparisons between front squat and back squat

There are a limited number of research studies conducted on the front squat exercise. Gullett et al. (2009) found out that the back squat showed higher compressive forces and knee extensor moments than the front squat. The research focused on the tibio-femoral (knee) joint kinetics and muscle activity to examine the change in the position of center of mass. The research was conducted on 15 individuals with a load mass of 70% of one repetition maximum. The result showed high average maximum compressive forces on the knee. The knee maximum compressive force of the front squat was 9.3 ± 1.5 N·kg^{-1}and the back squat was 11.0 ± 2.3 N·kg^{-1}. Knee maximum shear force of the front squat was - 4.9 ± 1.3 N·kg^{-1} and the back squat was -5.0 ± 1.5 N kg^{-1}. Mean maximum knee moments of the front squat was 0.7 ± 0.2 N·m·kg^{-1} and the back squat was 1.0 ± 0.4 N·m·kg^{-1}. In this research, an interesting result was that bar position did not influence muscle activity and muscle activity was different between ascending and descending phases. They concluded that there was more muscle activity during the ascending phase (Gullett et al., 2009). The knee is a very important joint. When squatting, the knee flexes and extends to activate muscles around the joint. However, the front squat, which requires a great deal of functional stability more than the back squat due to its unique technique and posture, has been neglected in the research area. A research study conducted by Russell and Phillips (1989) examined knee extensor demand and low back musculoskeletal risks during front and back squats. They hypothesized that the front squat had a greater low back injury risk than the back squat. Eight males with three years of weightlifting experience participated in their testing. A load mass was 75 percent of 1RM following 50 to 60% of 1RM for warm ups. Six joint markers, including one place at the end of weighted bar (shoulder) were placed on fifth metatarsophalangeal joint, lateral malleolus of the ankle, knee joint center axis, and greater trochanter of the femur. They used Newtonian equations of motion for their testing to examine joint forces and muscle moments, and they also used a five link system model that are linked from hip to lumbar 3-4 (pelvic) and from lumbar 3-4 to end of weight bar for shoulder (trunk). The results of their research study showed that the trunk angle of the front squat (65.0 ± 12.8°) and the mean maximum lumbar compressive force (105.6 ± 10.7 Nm) at the time of the maximal compressive force were lower than back squat's trunk angle (66.1 ± 8.9°) and mean maximum lumbar compressive force (111.4 ± 14.8 N) at the time of the maximal compressive force. Both lumbar shear force (69.1 ± 20.8Nm) and trunk angle (55.3 ± 10.8°) of front squat at the time of the maximal shear force were greater than the back squat's mean maximum lumbar shear force (67.3 ± 11.5Nm) and trunk angle (55.0 ± 8.9°) at the time of the maximal shear force. Russell and Phillips (1989) indicated that the inclination of the back might affect the low back joint and lead to injury, regardless the type of squatting exercise. The authors reported that more erect trunk posture minimized the trunk extensor moment, and the trunk inclination is a major determinant of lumbar compressive load. Trunk inclination had more influence on lumbar shear force than exercise type (Russell & Phillips, 1989). This research provides important findings between front and back squat exercises. There is other information on the internet, the magazine, and the media. However, most of information is unscientific and not a primary source. Thus, this research was conducted to help, practitioners and patients to provide safe and effective instruction on squat lifting.

Summary

Previous research studies have been conducted on the squat, particularly the back squat, because it is a widely used strength training exercise in the athletic population. However, research studies on the front squat have not been conducted in comparison with the back squat (Escamilla, 2001). There was also a lack of empirical evidence to compare the front squat and the back squat on how the body joints change when the load mass was increased. Due to the lack of empirical evidence, it is critical to examine the kinematic comparisons between the front squat and back squat in response to various load masses. If there was no significant difference found in this study, therapists, athletic trainers, and coaches could use the front squat and back squat interchangeably. However, if a significant difference was found, practitioners would need to consider carefully not only choosing which squat variation was prescribed for their patients but also selecting an appropriate load mass for their athletes. Therefore, the findings helped therapists and coaches to acquire a better understanding about squatting exercises, which enabled them to instruct their patients and athletes more effectively and safely.

METHODS

Participants

Eight experienced varsity male lifters (age 20 ± 0.8 years, height 1.85 ± 0.07 m, weight 106.6 ± 13.6 kg) participated in this study. Participants had weightlifting experience for at least five years prior to the study with previous experience in both squat exercises. This study was approved by the institutional ethics review board before conducting the experiment. All written consent forms were obtained from the participants prior to testing.

Experimental Setup

Thirteen joint reflective markers were placed on the right side of the body (sagittal plane) including participant's forehead, chin, shoulder (greater tubercle), elbow (lateral epicondyle of humerus), wrist (styloid process of the radius), hip (greater trochanter), knee (lateral epicondyle of the femur), ankle (lateral malleolus), toe (fifth metatarsal), spine of thoracic 6, lumbar 3, and sacrum 1, and end of the bar (Figure 2).

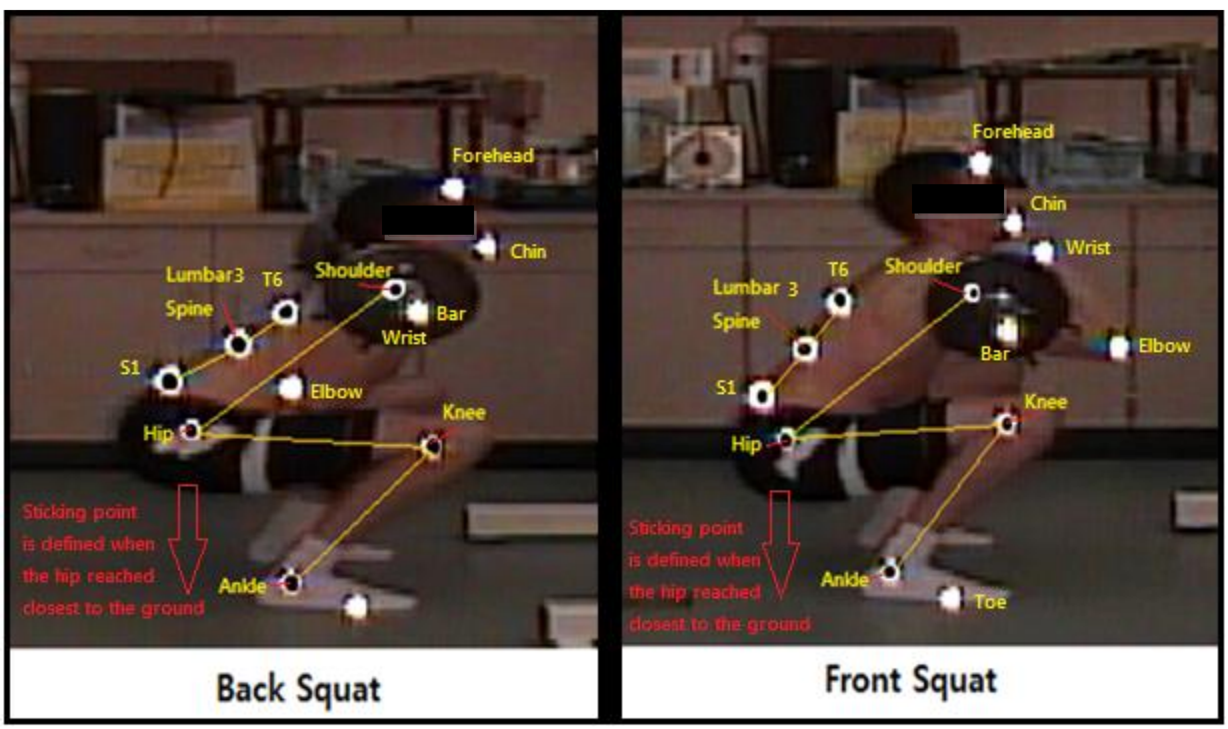

Figure.2 Marker placements at sticking position

An experienced weight lifting spotter was present during the testing to ensure the safety of participants. Data collection was conducted in one session and was approximately 45 minutes in duration for each participant in a session. A JVC video camera (Model: GR-D371V) was used to capture the kinematic movement at 60 frames per second in the sagittal view. In addition, a 650W artificial lighting was used to assist in identifying the joint reflective markers (Figure 3).

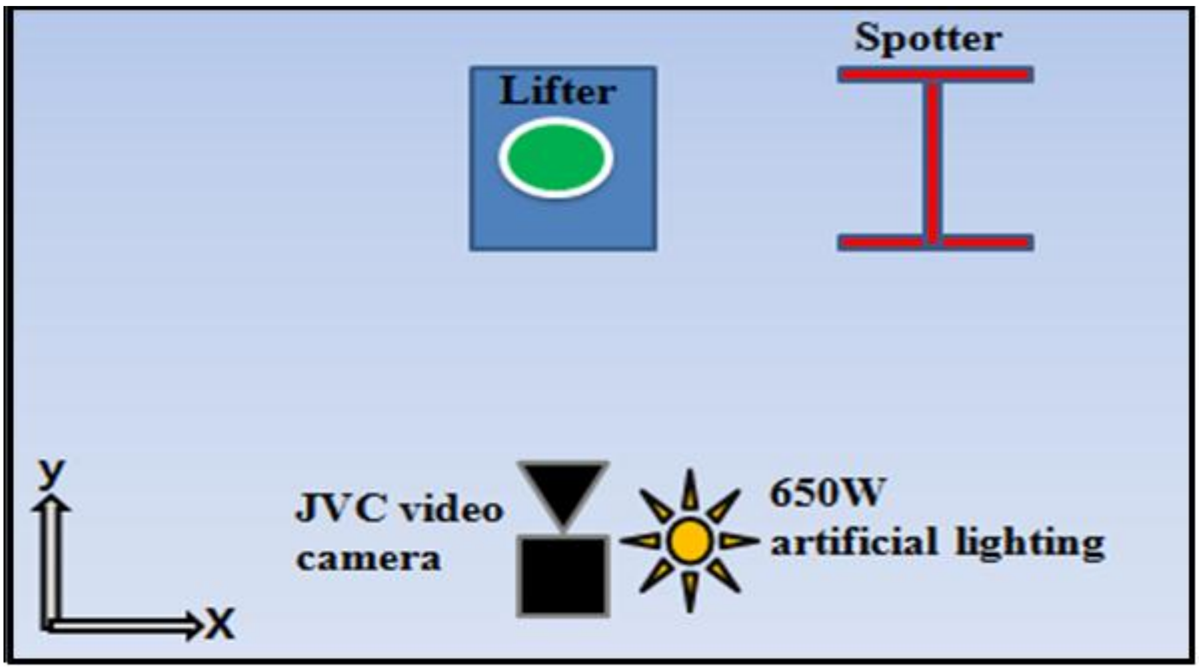

Figure.3 Experimental Set up

Participant Preparation

All participants performed one session of testing. During the session, participants performed a general warm up. They then were asked to perform one set of both the front squat and the back squat to familiarize themselves with the exercise and movement patterns. Then, each participant was asked to perform front and back squats four times of their 1RM while maintaining appropriate form.

Procedures

During the testing session, participants were asked to wear spandex shorts, no shirt and no shoes. Following a general warm up, the participants were asked to perform four repetitions at 65%, 75%, and 85% of 1 repetition maximum. The order of the front and back squat and load masses were randomly assigned to reduce the order effect. Recovery time between each of set of 4 reps was approximately three minutes and five minutes between squat types. The duration of the testing session was 45 minutes for each participant.

Data Processing

Since each participant performed each squat exercise at a specific load for four times, a total of 192 trials (8 subjects x 2 squats x 3 loads x 4 trials) were collected in this study. All video trials were transferred onto a computer in the Biomechanics Lab using Dartfish software. The first trial was eliminated and only the last three trials were used for data analysis to ensure the reliability of the data. One frame out of a total of 21 digitized frames (10 frames before and 10 frames after the sticking point frame of each trial) was used to determine as the sticking point, which was when the hip joint reached the maximum flexion angle. A standard two-dimensional kinematic analysis was conducted with Ariel Performance Analysis system (APAS) software. Kinematic variables of posterior trunk inclination, lumbar spine, hip, and knee joint angles and velocities (using central difference technique) were calculated at the sticking point. The digital filter function (x = 08 Hz / y = 08 Hz) was applied to reduce the noise of the data.

Statistical Analysis

A two-way (2 squats x 3 loads) repeated measures ANOVA was conducted at $\alpha = 0.05$ and followed by a *t*-test with Bonferroni adjustment if a significant difference was found. All statistical analysis was conducted with SPSS (v. 18) software**.**

RESULTS

A two-way (2 squats x 3 loads) repeated measures ANOVA was conducted at $\alpha = 0.05$ for the angular displacements of the lumbar spine, hip, knee, and trunk inclination. Using the Huynh-Feldt correction in the repeated measures ANOVA design, no statistical significant difference was found in the main effects (squat and load) and the interaction effect (squat x load) for the angular displacement of spine and hip (Appendix A). For the angular displacement of the knee and trunk inclination, no significant difference was observed in the main effect of load and the interaction effect between squat and load, but a significant difference was observed in the main effect of the squat type (Appendix A). Table 1 illustrates the angular displacements of spine, hip, knee and trunk inclination between front and back squats.

Table 1. Joint angles of the lumbar spine, hip, knee and posterior trunk inclination between squats at sticking point.

Comparisons	Mean (SD)°			*p*
Variations	Front Squat	vs.	Back Squat	
Lumbar Spine	174.6(2.4)	vs.	173.3(3.4)	0.14
Hip	66.1(12.2)	vs.	60.7(9.3)	0.13
Knee	63.9(9.8)	vs.	69.7(6.9)	0.01*
Posterior trunk inclination	35.8(7.1)	vs.	46.0(3.9)	0.01*

*Statistical significant at $p < 0.05$

A two-way (2 squats x 3 loads) repeated measures ANOVA was conducted at $\alpha = 0.05$ for the angular velocities of spine, hip and knee. Using the Huynh-Feldt correction in the repeated measure ANOVA design, no significant differences were observed in the hip and knee joints for both main effects of squat and load and also for the interaction effect between squat and load. For the angular velocity of the spine, the main effect of load and the interaction effect between squat and load did not show a significant difference, but a significant difference was observed in the main effect of squat type (Appendix B). Table 2 illustrates the angular velocities of lumbar spine, hip, and knee between the front and back squats.

Table 2. Angular velocities of the lumbar spine, hip and knee between squats at the sticking point

Comparisons	Mean (SD)°/s			*p*
Variations	Front Squat	vs.	Back Squat	
Spine	15.4(16.3)	vs.	67.1(56.5)	0.03*
Hip	23.7(15.0)	vs.	23.9(12.4)	0.94
Knee	13.8(17.7)	vs.	13.5(11.0)	0.96

*Statistical significant at $p < 0.05$

DISCUSSION

The purpose of this study was to investigate the kinematic analysis of the spine and lower extremity joints during the front and back squats in response to three different loads, 65%, 75%, and 85% of 1RM. Performing the squat exercise requires stability of the spine in order to maintain a proper posture. In a previous squat research study, the authors indicated that a significant amount of lumbar hyperextension was observed at the load of 60% and 80% of the maximum weight lifting capability, which is a cause for concern among the adult athletic population, particular for skeletally immature athletes (Walsh et al., 2007). However, in this research study, there was no statistical significant difference found at the lumbar spine angle when load masses were increased. In this study, the researcher hypothesized that the lumbar spine joint angle would increase as the load mass was increased; however, the results showed that the lumbar spine joint angle remained quite similar in all three different mass loads in both squat exercises.

List, Gulay, and Lorenzetti (2010) conducted a squat research study with movement science students, and the authors indicated that a decrease in the lumbar angle could be observed with an increase in load mass in the back squat exercise; however, this was not found in this research study. In this research study, experienced weight lifters participated, so up to 85% of 1 RM did not affect their lumbar angle. It is possible that subjects with less lifting experience may show a change in the lumbar angle.

Maduri et al. (2008) indicated that when a person performs the squat exercise, the lumbar curvature is influenced by the trunk inclination angle. Russell and Phillips (1989) further emphasized the importance of the anterior trunk inclination angle and indicated that one squat exercise was not superior to the other, and the risk of lower back injury was influenced by the anterior trunk inclination rather than by the type of squat exercise. Hence, in the study the researcher examined the posterior trunk inclination angle (Figure 4).

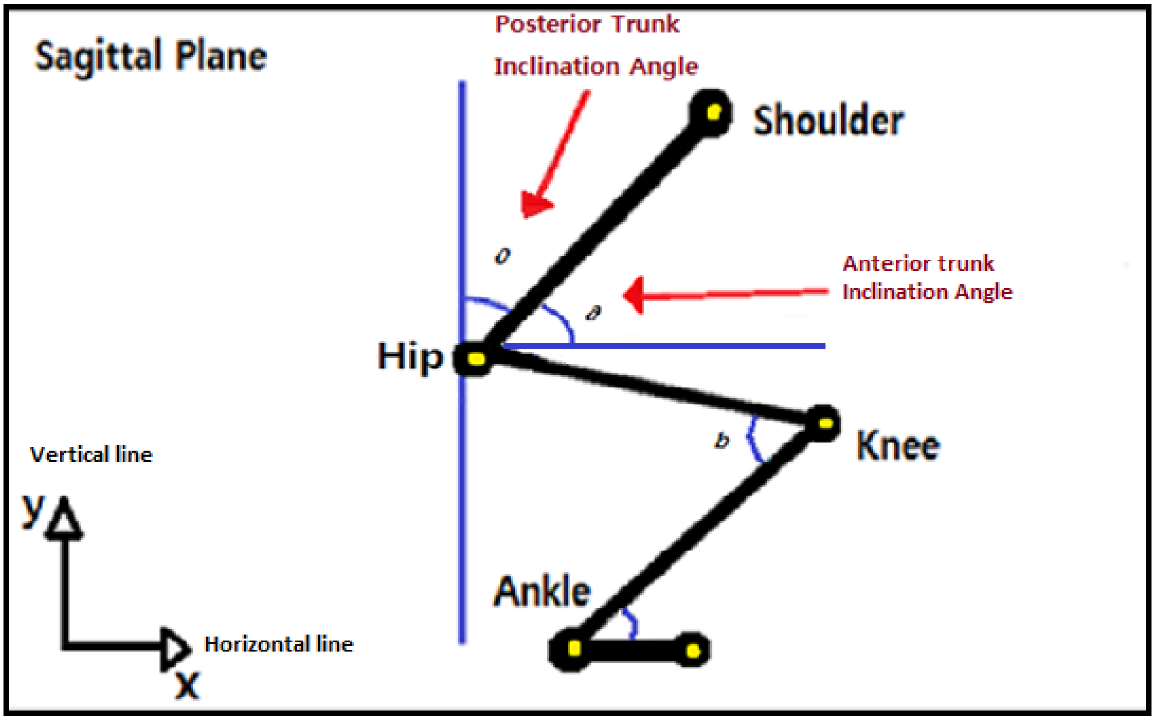

Figure 4. Posterior trunk inclination angle

Since a statistical significant difference was found in the posterior trunk inclination angle between front and back squat exercises, this research study indicates that type of squat has an effect on the posterior trunk inclination angle. The back squat showed a mean posterior trunk inclination angle of 46.0 ± 3.9° that is significant greater than the front squat mean posterior trunk inclination angle of 35.8 ± 7.1°. In addition, this research study showed a higher posterior trunk inclination angle (approximately 10 degrees higher) when compared to Russell and Phillips' (1989) study. The differences in the posterior trunk inclination angle may be due to different joint marker placements between two research studies. In this study, the researcher used the greater tubercle of the humerus and the greater trochanter of the femur to define the trunk inclination angle whereas in Russell and Phillips' (1989) study, the authors used the end of weighted bar as the shoulder joint and the anterior superior iliac spine of the hip to measure trunk inclination angle. Moreover, in this study subjects performed deep squat exercises for both front and back squats as opposed to the parallel squat performed in Russell and Phillips' (1989) study. Finally, the level of weight lifting skill was different between the two studies; top experienced weight lifters from a varsity football team participated in the study compared to the general experienced college students from Russell and Phillips' (1989) study.

Since in this study, the back squat exercise showed a greater posterior trunk inclination angle than the front squat exercise but with similar lumbar spine angles, this finding did not fully support the previous research that indicates when a person performs the squat exercise, the lumbar curvature is influenced by the trunk inclination angle (Maduri et al., 2008). Eleven general volunteers participated in Maduri et al. (2008) s' study, and it is very likely that subjects were less experienced than in the previous research study. Hence, the lumbar curvature was affected by the trunk inclination angle. Since experienced weight lifters participated in this study, these lifters were able to maintain a proper spine angle regardless of the load or type of squat, which was associated with the trunk inclination angle. A future kinetic research study is warranted to examine the lumbar spine angle in both experienced and inexperienced weight lifters.

The researcher hypothesized that there was a statistically significant difference in the angular displacement between back and front squats at the lumbar spine, hip, and knee. The results of this study showed that the front squat had a significant higher knee flexion angle than the back squat. However, in a previous research study the front squat was found to produce significantly lower maximal joint compressive forces at the knee as well as reduced lumbar stress as compared with back squats (Gullett et al., 2009). This previous research finding may not fully be supported by this research study since this study has found a higher knee flexion in the front squat, which may potentially result in a higher compressive force at the knee. However, a future kinetic research analysis will have to be conducted to further investigate and understand the joint compressive forces at the knee. Moreover, from the result of the study, it was also revealed that there was a statistical significant difference in the joint angular velocity at the lumbar spine between both squat exercises. The lumbar spine of the back squat exercise had a mean angular velocity of 67.09 ± 59.01°/s and was significantly greater than the front squat exercise of 15.42 ± 16.87°/s. This indicates that experienced weight lifters may experience a higher amount of compressive force at the lumbar region of the spine in the back squat exercise due to higher amount of angular velocity at the lumbar spine. However, since there was no significant difference at the lumbar spine angle between back and front squats, this study suggests that these experienced lifters were safe to perform the back squat exercise up to 85% of 1RM.

This research has some limitations that should be considered carefully. In this study, the researcher used the deep squat exercise rather than the parallel squat exercise. Different squat exercises have different sticking points, which would affect different lower extremity joint angles. Another major factor in this study is that the percentage of 1RM load mass was used instead of percentage load mass of subject's body weight. Therefore, the amount of joint muscle force that the subject executed may be different.

Additionally, in this study the subjects were top experienced weight lifters who were varsity football players, so the results may be different if a research study was conducted on actual Olympic weight lifters or general experienced college students. Finally, this study used male subject population, and the lower extremity joint angles may be quite different for the female subject population due to wider pelvic girdle and higher knee Q angle.

CONCLUSION

Eight experienced weight lifters participated in the study, and each participant performed both front and back squats at 65%, 75% and 85% of 1RM. The results of the study showed that the back squat has a significant greater posterior trunk inclination angle, less knee flexion and higher lumbar spine angular velocity in comparison with the front squat. Since the participants were experienced weight lifters, they were not in a risk of injury in performing back squat up to 85% of 1RM even with greater trunk inclination angle because their lumbar spine angle did not change significantly, which showed that their lifting technique was not compromised. This kinematic research study demonstrated the proper lifting technique for both front and back squat exercises. Excessive posterior trunk inclination angle may cause serious spine injury, particularly for less experienced weight lifters. Therefore, this study provides a crucial understanding about the front and back squat movements in response to different loads and suggests the importance of prescribing strengthening exercise targeting the knee joint in the front squat and the trunk stability in the back squat. Practitioners could utilize the findings from this study to help their athletes perform both front and back squats safely. Future studies are warranted to examine the kinematic differences between experienced and novice lifters, and also a kinetic analysis can be conducted to fully understand the compressive force in response to different load masses at the knee and spine.

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Appendix A: Angular Displacement Statistical Analyses

Lumbar Spine **-** Tests of within-subjects effects on spine

Effects (Huynh-Feldt)	**Mean Square**	**df**	**F**	***p***	**Eta Squared**	**Observed Power**
Squat	19.76	1.0	2.85	0.14	0.29	0.31
Error	6.94	7.0				
Load	2.19	1.4	0.19	0.75	0.03	0.07
Error	11.55	9.7				
Squat x Load	8.96	1.7	0.79	0.46	0.10	0.15
Error	11.28	12.2				

*Statistical significant at $p < 0.05$

Hip **-** Tests of within-subjects effects on hip

Effects (Huynh-Feldt)	**Mean Square**	**df**	**F**	***p***	**Eta Squared**	**Observed Power**
Squat	356.43	1.0	3.04	0.13	0.30	0.33
Error	117.09	7.0				
Load	20.92	1.9	20.92	0.23	0.19	0.28
Error	12.85	13.3				
Squat x Load	23.43	2.0	1.10	0.36	0.14	0.20
Error	21.41	2.0				

*Statistical significant at $p < 0.05$

Knee **-** Tests of within-subjects effects on knee

Effects (Huynh-Feldt)	**Mean Square**	**df**	**F**	***p***	**Eta Squared**	**Observe d Power**
Squat	395.54	1.0	12.21	0.01*	0.64	0.85
Error	32.40	7.0				
Load	21.79	2.0	1.84	0.20	0.21	0.32
Error	11.88	14.0				
Squat x Load	17.58	2.0	2.47	0.12	0.26	0.41
Error	7.12	14.0				

*Statistical significant at $p < 0.05$

Posterior Trunk Inclination **-** Tests of within-subjects effects on trunk

Effects (Huynh-Feldt)	**Mean Square**	**df**	**F**	***p***	**Eta Squared**	**Observe d Power**
Squat	1252.768	1.0	16.31	0.01*	0.70	0.93
Error	76.80	7.0				
Load	36.58	1.4	3.25	0.09	0.32	0.42
Error	11.25	9.7				
Squat x Load	12.41	2.0	1.28	0.31	0.15	0.23
Error	9.72	14.0				

*Statistical significant at $p < 0.05$

Appendix B: Angular Velocity Statistical Analyses

Lumbar Spine - Tests of within-subjects effects on spine

Effects (Huynh-Feldt)	**Mean Square**	**df**	**F**	***p***	**Eta Squared**	**Observed Power**
Squat	32033.33	1.0	7.06	0.03*	0.50	0.63
Error	4536.91	7.0				
Load	100.05	2.0	0.11	0.90	0.16	0.06
Error	892.59	14.0				
Squat x Load	28.45	2.0	0.04	0.97	0.01	0.05
Error	799.18	14.0				

*Statistical significant at $p < 0.05$

Hip - Tests of within-subjects effects on hip

Effects (Huynh-Feldt)	**Mean Square**	**df**	**F**	***p***	**Eta Squared**	**Observed Power**
Squat	1.050	1.0	0.01	0.94	0.00	0.05
Error	150.61	7.0				
Load	116.06	2.0	0.56	0.59	0.07	0.12
Error	209.15	14.0				
Squat x Load	195.93	1.1	0.80	0.41	0.10	0.13
Error	243.77	7.8				

*Statistical significant at $p < 0.05$

Knee - Tests of within-subjects effects on knee

Effects (Huynh-Feldt)	**Mean Square**	**df**	**F**	***p***	**Eta Squared**	**Observed Power**
Squat	1.33	1.0	0.03	0.96	0.00	0.05
Error	423.61	7.0				
Load	131.06	2.0	0.98	0.40	0.12	0.19
Error	133.21	13.7				
Squat x Load	119.35	1.42	0.56	0.53	0.07	0.11
Error	212.88	9.91				

*Statistical significant at $p < 0.05$

Appendix C. Joint angles of lumbar spine, hip, knee, and posterior trunk inclination

Comparisons	Mean (SD)°		
Lumbar Spine			
FS vs. BS (65%)	175.0(1.2)	vs.	172.2(3.9)
FS vs. BS (75%)	174.4(2.7)	vs.	173.4(4.1)
FS vs. BS (85%)	174.3(3.1)	vs.	174.3(1.8)
Hip			
FS vs. BS (65%)	64.4(9.7)	vs.	61.1(9.3)
FS vs. BS (75%)	67.2(14.6)	vs.	62.3(10.4)
FS vs. BS (85%)	66.9(13.3)	vs.	58.7(9.0)
Knee			
FS vs. BS (65%)	62.6(7.5)	vs.	68.7(6.8)
FS vs. BS (75%)	63.0(11.1)	vs.	70.6(5.8)
FS vs. BS (85%)	66.2(11.4)	vs.	69.7(8.7)
Posterior Trunk Inclination			
FS vs. BS (65%)	35.9(6.5)	vs.	44.7(3.7)
FS vs. BS (75%)	35.1(7.8)	vs.	44.9(4.5)
FS vs. BS (85%)	36.2(8.0)	vs.	48.4(2.3)

Appendix D. Angular velocities of the lumbar spine, hip, and knee

Comparisons	**Mean (SD)°/s**
Lumbar Spine	
FS vs. BS (65%)	17.5(18.7) vs. 70.7(56.3)
FS vs. BS (75%)	12.7(15.4) vs. 65.9(58.2)
FS vs. BS (85%)	16.1(16.5) vs. 64.7(62.5)
Hip	
FS vs. BS (65%)	21.1(10.4) vs. 27.3(17.4)
FS vs. BS (75%)	22.6(12.8) vs. 19.3(6.5)
FS vs. BS (85%)	27.3(21.0) vs. 25.3(10.9)
Knee	
FS vs. BS (65%)	9.6(6.9) vs. 11.7(7.8)
FS vs. BS (75%)	15.0(13.6) vs. 17.48(16.3)
FS vs. BS (85%)	16.9(27.7) vs. 11.2(6.6)