Comparison in Joint Angles and Joint Forces Between the Safety-Squat Bar and Traditional Barbell Back Squat

A thesis submitted in partial fulfillment of the requirements
For the degree of Master of Science in Kinesiology

By

David Johansson

December 2020
The thesis of David Johansson is approved:

_________________________________________  ____________________________
Paulo Marchetti, Ph. D.  Date

_________________________________________  ____________________________
Shane Stecyk, Ph. D.  Date

_________________________________________  ____________________________
Sean P. Flanagan, Ph. D., Chair  Date

California State University Northridge
ACKNOWLEDGEMENTS

I would like to thank Dr. Flanagan and the Kinesiology department at California State University, Northridge, CA. I would like to thank the Strength and Conditioning staff at CSUN for letting us use their equipment during this research. I would also like to thank the many generous participants who volunteered their valuable time to make this possible. A special thanks goes out to Anna Anka for assisting and helping to get all this done.
Table of Contents

Signature Page                                      ii
Acknowledgements                                   iii
Abstract                                           vi
Section 1: Introduction                            1
Problem statement                                  5
Section 2: Literature review                       6
  Squat training, Squat 1RM and                    6
  improvement in sport performance
Joint kinematics                                    9
  Ankle                                            9
  Knee                                             9
  Hip/Trunk                                        10
Joint kinetics                                      13
  Ankle                                            13
  Knee                                             13
  Hip/Trunk                                        15
Muscle EMG during different squat variations       17
Summary and conclusions                            19
Research hypotheses                                20
Section 3: Methods                                 21
  Experimental Approach                            21
Participants 22
Procedures 24
  First test session 24
  Second session 26
  Third session 26
  Outline of testing protocol 27
  Instruments 27
Statistical Analysis 29
Section 4: Results 30
  Joint angles 30
  Joint moments 31
  Joint moment work 31
Discussion 33
Practical application 37
Section 5: References 38
Appendix A: Informed consent form 42
Appendix B: Questionnaire 48
Appendix C: Video release form 49
Appendix D: Modified PAR-Q 50
Appendix E: Student health center 52
Appendix F: Participant information 53
Abstract

Comparison in Joint Angles and Joint Forces Between the Safety-Squat Bar and Traditional Barbell Back Squat

By David Johansson

Master of Science in Kinesiology

The primary objectives for this investigation were to compare the kinematic and kinetic differences between performing a parallel back squat using a Traditional Barbell (TB) or a Safety-Squat Bar (SSB) while using the same foot-stance for both barbells. Fifteen healthy males who were experienced at performing the barbell back squat (23.13 ± 3.93 years of age) performed back squat with traditional barbell and a safety squat bar at 85% of their respective 1RM with each barbell. A 3x2 Factorial ANOVA with repeated measures was used to determine the kinetic and kinematic differences between the exercises. Results showed that the TB exercise experienced significantly greater maximum hip angle (P < .001; d = 1.80), maximum hip net joint moment (P = .001; d = 1.10), hip net moment work (P = .002 ; d = .97) and maximum ankle net joint moment (P = .029; d = 0.63), while also lifting significantly (P = .005; d = .858) more weight than the SSB exercise. The SSB exercise experienced significantly higher maximum knee angles (P = .011; d = .75) than the TB exercise. The results suggest that the SSB may be preferred to the TB in reducing maximum hip angles, while the TB may be preferred to the SSB for developing the hip extensors and lifting higher maximum loads. Future research should consider comparing the biomechanical differences between the SSB back squat and a TB front squat, or compare all three (TB back squat, SSB back squat and TB front squat), as well as testing for EMG during these different squat variations.
Section 1: Introduction

Athletes and recreational weightlifters utilize the squat to improve their performance, enhance their fitness and/or reduce their risk of injury (9,18). Athletes often use the loaded barbell squat as a tool to improve lower body strength and improve sport performance (9,17,23). The research supports the squat as an effective exercise to improve jump height, sprint speed, and leg power in a variety of populations (4,5,6,21). The squat is also used in rehabilitation settings (11), where it has been shown to be effective in the rehabilitation of ACL injury (18) as well as decreasing overall injury risk in athletes (9).

However, when a person is performing the loaded barbell squat, both the knee and the lumbar spine are subject to increased risk of injury (1,3,8,10,20). The loaded squat increases tibiofemoral compressive forces, which can increase the risk of injuries to the menisci and articular cartilage in the knee if the weight lifted is excessive (10). While some forward lean of the trunk is necessary during the squat to keep the center of mass of the barbell over the base of support (the feet), excessive forward trunk lean during the squat has been shown to increase the shear forces at the lumbar region. According to expert opinion, although stress is important for adaptations to occur, excessive stress could potentially increase the risk of injury to the lower back while squatting with heavy loads (8,10,17).

Two common variations of the squat used by strength and conditioning coaches to improve the performance of athletes are the barbell back squat and the barbell front squat (12,19,25). Gullett et al. (12) compared the net force and torque on the knee joint during the back and front squat and found that the back squat resulted in significantly higher compressive forces on the knee joint (11.0 ± 2.3 N·kg⁻¹) than the front squat (9.3 ± 1.5 N·kg⁻¹). The increased compressive forces on the knee joint during the back squat were attributed to the increased loads
that the participants lifted during the back squat (61.8 ± 18.6 kg) compared to the front squat (48.5 ± 14.1 kg)\textsuperscript{12,25}. Gullett et al. (12) found no significant difference in electromyography (EMG) activation between rectus femoris, vastus lateralis, vastus medialis, biceps femoris, semitendinosus and erector spinae, although the absolute load varied between the two lifts. Therefore, they suggested that the front squat could achieve similar muscular stimulation at lower absolute loads than the back squat, which would decrease stress on the knee joint. Yavuz et al. (25) hypothesized that the reason Gullett et al. (12) did not find any significant difference in muscular EMG activity between the front and back squat was because Gullett et al. (12) only used 70\% of the participants’ 1 repetition maximum (1RM) weight during the study. In response, they conducted a study using the participants’ 1RM during their testing. Yavuz et al. (25) found that the maximum load lifted was higher during the back squat than the front squat (109.17 ± 25.51 kg versus 85.00 ± 15.67 kg, P < 0.05). EMG activation of the semitendinosus was greater during back squats than front squats (29.0 ± 16.2 % versus 18.4 ± 10.1 % of MVIC, P < 0.05), and EMG activation of the vastus medialis was greater during front squats than back squats (58.9 ± 17.1 % versus 49.3 ± 13.9 % of maximum voluntary isometric contraction (MVIC), P < 0.05).

The findings in Yavuz et al. (25) study indicated that the back squat might be better for developing the hamstrings, while front squats might be better for developing the quadriceps. There was no difference in EMG activation in the gluteus maximus between the back and front squat (37.1 ± 23.5 % versus 37.2 ± 27 % of MVIC, P = 0.959). Both Gullett et al. (12) and Yavuz et al. (25) found that the back squat resulted in significantly greater forward trunk lean compared to the front squat. This finding is supported by additional research comparing front and back squat kinematics (2,8). Since increased forward lean of the trunk may increase the
forces exerted on the lumbar spine, the front squat is believed to be a safer alternative for the lower back than the back squat. (8,12,25).

There are two variations of the back squat that are frequently used by athletes, the high-bar back squat (HBBS) and the low-bar back squat (LBBS) (24). The HBBS is the most common variation and is typically used by athletes to improve lower body strength, while the LBBS is often used by powerlifters, whose goal is to lift as much weight as possible (22). According to Wretenberg et al. (24), the barbell position during the HBBS is characterized by placing the barbell slightly below the spinous process of the C7 vertebra, while the barbell positioning during the LBBS is lower down on the back across the spine of the scapula. A study by Wretenberg et al. (24) compared the HBBS and LBBS in nationally competitive weightlifters (HBBS) and powerlifters (LBBS). They found significant differences in kinetics and kinematics between the two techniques. The HBBS is performed with a more upright torso than the LBBS, resulting in a higher knee moments and lower hip moments than the LBBS. During the LBBS, the torso is more horizontal compared to the torso position of the HBBS, resulting in higher torques about by the hip compared to the knee. These results indicate that the HBBS might exert higher torques about the knee while reducing the stress placed on the lower back due to its more upright torso positioning, and suggest that the HBBS is in between the LBBS and the front squat in terms of forces exerted on the knee and lower back. The LBBS may reduce the stress on the knee joint, while increasing the stress placed on the hip and lower back (24).

A study performed by Lander et al. (15) found that performing a back squat with a modified barbell with a lower center of mass decreased the intra-abdominal pressure (IAP) compared to back squatting with a traditional barbell (TB). An increase in IAP has been correlated to increased disc pressure (16). Therefore, the decrease in IAP during the modified
barbell back squat may reduce the stress on the spine compared to a regular barbell back squat (15).

A standard Olympic traditional barbell (TB) used for squatting weighs 20.5kg (25). Alternative and modified bars exist that might alter the squat mechanics and perhaps make the loaded squat safer (15). One of these modified bars is the Safety-squat bar (SSB). The SSB weighs 65 pounds (Elitefts, London, Ohio) and it has been suggested that the pads on the barbell could lead to a higher barbell position on the upper back than the TB and its cambered structure may have a lower center of mass than the TB. However, there is no research to support this.

Two handles are attached to the SSB, which places the arms in a similar position as the front squat, with the hands in front of the chest (12,25). Such hand placement may be beneficial for athletes or weightlifters who suffer from shoulder injury or poor shoulder mobility that prevent them from squatting with their arms in a TB back squat position, but no known research exists to confirm this idea. The SSB is padded, and the inverted U shape that goes around the lifters’ upper back makes the SSB balance on the lifter’s upper back. It is possible to squat, lunge, and perform step-ups with the SSB without holding onto the bar. Besides the possible benefits of the hand positioning for people with injured or limited shoulder mobility, the SSB may change the joint angles and the biomechanics of the back squat due to the possible higher barbell position, altered hand position, and lowered position of the bar’s center of mass (2,8,12,15,24,25). These differences may have kinetic and kinematic advantages over the TB. There are many ideas about the benefits of the SSB, but there is currently no known scientific evidence to support them.
Problem statement

The loaded squat exercise has been shown to improve performance in athletes of different skill levels (4,5,6,21), and there are different variations of the squat that strength coaches utilize depending on the athletes’ needs and goals (12,25). The SSB is gaining popularity among strength and conditioning coaches due to its different positioning of the arms and the lower positioning of the center of mass of the barbell. Fitness and strength and conditioning professionals are developing several ideas about the benefits of using the SSB, but there is no empirical evidence behind them. Diggin et al. (8), Gulle et al. (12) and Yavuz et al. (25) showed that barbell positioning (front or back) as well as high-bar or low-bar techniques (22,24) could affect the trunk and hip angle. A study by Lander et al. (15) found indications of less spinal stress when squats are performed with a lowered position of the center of mass of the barbell. The current research showed kinetic and kinematic differences during the front, high-bar, low-bar back squat and squatting with a modified center of mass barbell (2,8,12,15,22,24,25).

The SSB is positioned higher on the trapezius than a traditional barbell and the anterior hand position shifts the center of mass anteriorly compared to a regular back squat, which may result in a more upright torso during the SSB back squat compared to a back squat using the TB. This could decrease the risk of lower back injury during the back squat (2,8,10,12,22,24,25).
Section 2: Literature review

Squat training, Squat 1RM and improvement in sport performance

The squat is an important and popular exercise among athletes and recreational lifters to improve their sport performance and strength (9,17,23). The effectiveness of the squat to improve leg power, sprint speed and vertical jump height have been investigated by multiple research teams (4,5,6,21). Chelly et al. (5) divided 22 young soccer players (mean age 17 years old) into two groups: one resistance training group (RTG) and one control group (CG). The RTG performed two resistance training sessions per week for two months. Back half squats were during the resistance training sessions. The strength training session consisted of back half squats, with 7 repetitions at 70% of 1RM, 4 repetitions at 80% of 1RM, 3 repetitions at 85% of 1RM and 2 repetitions at 90% of 1RM. The 70% load was considered a warm up exercise. The participants were tested in leg power, leg and thigh muscle volume and cross sectional area (CSA), squat 1RM, squat jump (SJ) height, countermovement jump (CMJ) height, five jump test (5-JT) distance, as well as a 40m sprint test where different running velocities were measured. The RTG significantly improved all outcomes measured compared to the CG, except for the CMJ height, leg and thigh muscle volume and cross sectional area.

Channell et al. (4) compared three different training methods and their effect on vertical jump height. The different training methods were Olympic weightlifting (OT), traditional resistance training (RT), and a control group (CG). The OT group performed more explosive lifts such as power clean and push jerk, while the RT group performed more traditional power-lifting exercises such as squat and deadlift. Twenty-seven high-school football athletes participated in the study. The intervention groups trained three days per week for 8 weeks. Both the OT and RT
groups saw small but significant improvement in vertical jump height compared to the CG, with the OT group experiencing a non-significant 56% increase in jump height over the RT group.

Another study investigated the effects of a 6-week, 12 sessions resistance training program on squat 1RM and sprint performance in professional soccer players. Seventeen soccer players participated. The exercises performed were back squats, Romanian deadlifts and Nordic lowers. (21). The participants improved their 5, 10 and 20m sprint times as well as their absolute and relative 1RM back squat. There was a correlation between the improved squat strength and improved sprint speed, but since no control group was used, it is impossible to know if the improvement in sprint speed was a result of the resistance training, playing soccer in-season, or a combination of both.

Comfort et al. (6) performed a study on how maximal squat strength changes sprint performance in 19 professional rugby players. The intervention lasted eight weeks (4 weeks strength mesocycle and a 4 week power mesocycle), and the participants performed resistance training twice a week, in addition to two plyometric and agility training sessions per week. During the strength mesocycle a workout could consist of back squats, mid-thigh clean pull, Romanian deadlift and Nordic curls. During the power mesocycle a workout could consist of hang power clean, squat jumps, back squats and Nordic curls. The players significantly improved their absolute and relative 1RM back squat, as well as their 5, 10 and 20m sprint times. Just as in the study by Styles et al. (21), no control group was used and therefore it is not certain that the improvement in sprint speed was due to the improved leg strength. Together with an agility and plyometric training program, improving back squat strength led to significantly improved 5, 10 and 20m sprint times (6).
Improving back squat performance appears to improve sport performance outcomes such as improved sprint speed, jump height and power (4,5,6,21). Chelly et al. (5), Comfort et al. (6) and Styles et al. (21) all saw improvements in sprint performance, and both Channell et al. (4) and Chelly et al. (5) saw improvements in jump performance in athletes performing back squat strength training compared to control groups.
Joint kinematics

Ankle

There is currently little research on how the kinematics of the ankle joint is affected by squatting technique. Braidot et al. (2) studied 10 males who performed both the front and back squat. They compared the joint angles of the ankle, knee and hip and found no significant differences in the joint angles in the ankle joint between the front and back squat (2). The authors did not define the depth of the two squat variations, but previous research has shown that increased squat depth produces increased dorsiflexion at the ankle (14).

Knee

Several studies have looked at the difference in kinematics at the knee joint during the front and back squat (2,8,25), and Wretenberg et al. (24) compared knee kinematics between high-bar back squat (HBBS) and low-bar back squat (LBBS). Neither of these studies showed any significant differences in knee angle between front and back squat, or between HBBS and LBBS.

Lander et al. (15) investigated the biomechanics of the back squat using a modified center of mass bar. Six male participants with experience performing the squat exercise participated in the study. All six participants performed five squats using their estimated 5RM during three different conditions. One condition used a traditional barbell, the second and third condition used an “inverted U-bar” which lowered the center of mass of the barbell. Kinematic data showed no significant differences in the knee angle between the three conditions. The current evidence suggests that the position or load of the barbell does not affect the knee angle during different squat variations (2,8,15,24,25).
Several studies have shown that the back squat is characterized by a significantly greater forward trunk lean/increased hip flexion compared to the front squat (8,25). Diggin et al. (8) did not mention any standardization of the barbell position during the back squat (high or low), and the load used during their testing was relatively low (50% of back squat 1RM). Both squat variations used the same absolute weight. This could affect the outcome, since the relative weight for the front squat is higher and may cause an increase in forward trunk lean, since forward trunk lean increases at higher intensities (13). According to Kellis et al. (13), there may have been larger effects between the two squat variations if the participants used higher intensities, since that would increase the forward trunk lean, especially during the back squat.

Yavuz et al. (25) showed a significant increase in forward trunk lean in the back squat compared to the front squat. The participants performed one squat repetition at their predetermined 1RM for each respective squat condition, with the barbell standardized to the high barbell position during the back squat. This might be a more accurate testing method than using the same absolute load since the maximum weight lifted is different between the two squat techniques (12,25).

One study contradicts the results of Braidot et al. (2), Diggin et al. (8) and Yavuz et al. (25), showing no significant differences in trunk angle between the front and back squat (17). Russel and Phillips (17) tested the difference in knee extensor moments, trunk extensor moments, and trunk angle for the front and back squat in eight college-aged male individuals with a minimum of three years weightlifting experience. The results showed large individual differences between participants, with the mean results showing no significant difference in trunk inclination angle between the front and back squat. One reason Russel and Phillips (17)
achieved different results than other studies (2,8,25), may be because they used the same absolute load (75% of front squat 1RM), which would indicate that the relative weight for the front squat was higher, since people typically lift more weight with the back squat technique than the front squat technique (12,25). Since the relative weight for the front squat was higher than during the back squat, it is possible that the front squat technique caused increased forward trunk lean due to the higher relative load used during the front squat (13). Russel and Phillips (17) also didn’t identify several key aspects of the squat, such as depth of the squat and the exact barbell positioning during the two squat variations. Therefore, it is not clear if some participants used the LBBS while some used the HBBS. Such difference in barbell position can significantly affect the trunk positioning during the back squat (24).

Wretenberg et al. (24) compared joint kinetics and kinematics between the HBBS and LBBS using weightlifters (Olympic weightlifters) and powerlifters. The technique required for the two squat variations is different and the participants were specialized in performing only one of the two variations. That being the case, the participants performed the squat variation they were specialized in, HBBS for the weightlifters or the LBBS for the powerlifters. Wretenberg et al. (24) defined the HBBS position of the barbell to be slightly below the spinous process of the C7 vertebra, while the barbell positioning during the LBBS is lower down on the back, across the spine of the scapula. Both the weightlifters and powerlifters performed two depths with their chosen squat technique: the parallel and the deep squat. The parallel squat was defined as having the posterior borders of the hamstrings parallel to the ground, while the deep squat was defined as maximum flexion at the knees (24). The results showed that both groups increased the flexion at the hips as they reached a deeper squat (parallel vs. deep squat). The LBBS showed a significant increase in forward lean of the trunk compared to the HBBS.
The current evidence suggests that the front squat technique is characterized by less trunk flexion than the back squat technique, and the HBBS variation maintains a more erect trunk compared to the LBBS (2,8,24,25). This difference in trunk angle between squat techniques indicates that the HBBS may be safer for the lower back compared to the LBBS, and the front squat may be a safer alternative for the lower back than the back squat technique (8,10,17).
Joint Kinetics

Ankle

Braidot et al. (2) investigated the difference in ankle moments between the front and back squat and found no significant difference in the moment forces of the ankle joint. No significant differences were found in ankle joint moments using a modified center of mass bar compared to a traditional barbell (15).

Knee

Several studies have researched the differences in knee kinetics between the front and back squat (2,12,17). Braidot et al. (2) and Russel and Phillips (17) both used the same absolute weight for both squat conditions (50% of back squat 1RM and 75% of front squat 1RM, respectively). Gullett et al. (12) and Yavuz et al. (25) used the same relative load based off the subjects’ 1RM (70% and 100%, respectively). The participants in the study of Braidot et al. (2) performed four repetitions at 50% of their back squat 1RM for both the front and back squat. Overall, the knee extensors did more work during the front squat compared to the back squat. This indicates that the front squat may achieve greater muscular demand at the knee compared to the back squat while using the same load (2).

Russel and Phillips (17) also used the same absolute load for the front and back squat, with the participants performing three repetitions of each condition with 75% of their front squat 1RM. Unlike Braidot et al. (2), Russel and Phillips (17) did not find a significant difference in knee extensor moments between the two squat techniques, suggesting that there may be no difference in knee extensor development between the two conditions.

Gullett et al. (12) also compared the biomechanics of the back and front squat. Fifteen participants (9 male, 6 female) experienced in both lifts performed three repetitions at each
condition at 70% of their respective 1RM. The participants lifted significantly greater loads during the back squat than the front squat (mean 61.8kg versus 48.5kg). The kinetic data showed a significant increase in compressive forces on the tibiofemoral joint in the back squat, with average compressive forces of 11.0 N·kg⁻¹ (back squat) and 9.3 N·kg⁻¹ (front squat). No difference in shear forces of the tibiofemoral joint was found between the front and back squat. There was also a significant increase in mean maximum knee moments, with back squat eliciting higher mean maximum knee moments than the front squat (1.0 N·m·kg⁻¹ versus 0.7 N·m·kg⁻¹).

Yavuz et al. (25) discussed that the increase in compressive forces during the back squat was probably due to the higher loads used during the back squat, and not because of the biomechanics of the two technique variations, since knee kinematic data has been shown to be similar between the two techniques (2,8,25). It could be speculated that the increase in mean maximum knee moments in the back squat compared to the front squat is because of the higher absolute load lifted in the back squat compared to the front squat.

In comparing the HBBS and LBBS between weightlifters and powerlifters, Wretenberg et al. (24) found that the two techniques significantly differed from each other in knee joint kinetics. The weightlifters performing the HBBS experienced mean maximum peak moments at the knee joint of 191 Nm (deep squat) and 131 Nm (parallel squat). For the powerlifters, those moments were 139 Nm (deep) and 92 Nm (parallel). The powerlifters were heavier and lifted heavier loads than the weightlifters that performed the HBBS. This indicates that the reason for the decreased knee moment in the LBBS is because of the technique difference, since knee moments were lower during the LBBS, although the load lifted was higher than the HBBS group. Lander et al. (15) found no difference in the maximum knee joint moments between the
regular barbell squats compared to squatting with a modified center of mass bar for either of the modified conditions.

The results in the studies comparing front and back squat are not conclusive, and no strong conclusions can be drawn from these results. It seems like there are small kinetic differences in the knee joint between the front and back squat. The HBBS and LBBS seem to have significant kinetic differences, with the HBBS producing higher moments at the knee joint than the LBBS (24). The current data suggest that with the same absolute load, the knee joint moment may do more work during the front squat compared to the back squat (1). When comparing the front and back squat using the same percentage of their 1RM for each squat variation, the back squat may increase the compressive forces at the tibiofemoral joint due to the higher absolute load used compared to the front squat (12). Squatting with a modified center of mass barbell does not seem to affect the knee moments during the back squat (15).

**Hip/trunk**

Several studies have investigated the kinetics of the hip and trunk during different squat variations. Braidot et al. (2) and Russel et al. (17) compared the hip and trunk kinetics between front and back squat. Russel et al. (17) did not find a significant difference in trunk extensor moments between the two squat techniques. The results in trunk extensor moments varied greatly between participants, and it was found that squat technique did not affect the trunk extensor moments, but the inclination of the trunk did. Participants squatting with a greater flexion of the trunk increased the maximum trunk extensor moment, no matter the squat condition.

Braidot et al. (2) found that the absorbed mean power at the hip was significantly greater during the back squat than the front squat (13.45% greater). This increase in absorbed mean power is associated with the increased speed of the squat during the exercise with the same load.
No differences were found in knee or ankle kinetics, therefore the increase in mean absorbed power might be a result of the increased hip flexion and forward lean of the trunk associated with the back squat compared to the front squat (8,25).

Wretenberg et al. (24) found that hip joint kinetics were significantly different between the HBBS and LBBS. The weightlifters performing the HBBS experienced mean maximum peak moments at the hip joint of 230 Nm (deep squat) and 216 Nm (parallel squat). For the powerlifters, those moments were 324 Nm (deep) and 309 Nm (parallel). Since the powerlifters were heavier and lifted heavier loads than the weightlifters that performed the HBBS, this finding could be attributed to the heavier loads lifted during the LBBS. However, the results of the knee moments indicate that the difference in hip and knee moment between the two squat variations is due to technique, since the higher loads lifted during the LBBS still elicited lower knee moments than the HBBS.

Russel et al. (17) found that the inclination of the trunk, not squat variation, was the important factor affecting trunk extensor moments. Greater forward lean of the trunk elicited higher trunk extensor moments, independent on squat variation. Typically the front squat is performed with a more upright torso than the back squat (8,25), but if a participant performs a front squat with a greater trunk flexion than during a back squat the trunk extensor moments would be greater during the squat variation eliciting the greatest forward lean (2). Wretenberg et al. (24) found that the LBBS placed higher moments on the hip than the knee extensors, while the HBBS moments were more evenly divided between the knee and hip moments.
Muscle EMG during different squat variations

A few studies have compared how the position of the barbell affects the muscular activation between front, back, low bar and high bar back squats (7,12,24,25). Contreras et al. (7), Gullett et al. (12) and Yavuz et al. (25) all compared muscular EMG activity between the front and back squat. All three studies used a relative weight based on the subjects’ 1RM (12,25) or 10RM (7). Both Contreras et al. (7) and Gullet et al. (12) did not find any significant differences in muscular activity between the front and back squat.

Contreras et al. (7) investigated the EMG activation in 13 experienced and resistance trained females during the parallel and full back squat, as well as the front squat. The back squat used the high barbell positioning. The participants performed 10 repetitions at their 10RM for both the parallel, full, and front squat. Mean and peak EMG activation were measured, with no significant differences in muscular EMG activation (upper gluteus maximus, lower gluteus maximus, biceps femoris and vastus lateralis) between the parallel, full, and front squat.

The results in the studies by Gullett et al. (12) and Contreras et al. (7) do not concur with the findings of Yavuz et al. (25), who found significantly higher EMG activation in the vastus medialis during the front squat and significantly higher EMG activation in the biceps femoris during the back squat. Contreras et al. (7) mentioned in the discussion that their study might have been underpowered since they found a 21.5% increase in peak EMG activation in the vastus lateralis during the front squat compared to the parallel back squat. Wretenberg et al. (24) found that the muscular EMG activity (vastus lateralis, rectus femoris and biceps femoris) was greater for the powerlifters performing the LBBS. Since the powerlifters lifted heavier absolute loads than the weightlifters, the EMG activity cannot accurately be compared between powerlifters and weightlifters.
According to Gullett et al. (12) and Contreras et al. (7), the front squat can elicit the same muscular activation as the back squat, while using a lower absolute load. The front squat technique exhibits a more upright trunk position than the back squat (8,25). This could be beneficial for athletes and recreational lifters, since increased load lifted increases the compression at the knee and an increased forward trunk lean increases the stress on the lower back (8,10,17). Yavuz et al. (25) on the other hand, believe that the front squat might be better for developing the knee extensors, while the back squat might be better for developing the hip extensors.
Summary and conclusion

The back squat may be used as an effective tool to help increase sprint speed, jump height and leg power among athletes (4,5,6,21).

A higher load can be lifted during the back squat than the front squat (12,25) and the back squat is characterized by greater forward trunk lean compared to the front squat (2,8,25). The LBBS is characterized by a greater forward lean of the trunk and a greater use of the hip moment extensors than the HBBS, while the HBBS divides the moments more evenly between the knee and hip (24). The front squat might be advantageous over the back squat in people who suffer from low back problems, and the HBBS seems to produce less stress on the lower back than the LBBS (8,12,24,25). The LBBS technique might be better than the front squat and HBBS in developing the hip extensors (24,25). There are currently no known research investigating the kinetic and kinematic differences between the SSB and a TB. This study will investigate if there are any kinetic and/or kinematic differences between the SSB and TB during a back squat.
Research hypotheses

Performing a parallel back squat with a safety-squat bar will lead to reduced forward trunk lean, increased knee moments and decreased hip moments compared to performing a parallel back squat with a traditional barbell in people experienced performing a back squat.
Section 3: Methods

Experimental Approach to the Problem

Fifteen male participants performed a total of three squat sessions. The first two sessions were used to determine their 1RM with each barbell, and each 1RM test was separated by a minimum of 72 hours. On the third session each participant performed eight back squat repetitions at 85% of their tested 1RM with both barbell variations (the 85% was rounded up or down to the nearest 2.5kg). The starting barbell variation was determined through counterbalanced randomization. The participant’s performed their back squats with a forceplate underneath their right leg while infrared cameras filmed their trials.

Sample rate for the camera and forceplates were 250 Hz and 5000 Hz, respectively.

Kinetic and kinematic differences were examined through maximum flexion angles, peak moments and work at the ankle, knee and hip with each barbell condition. A 3x2 Factorial ANOVA with repeated measures was used to determine the kinetic and kinematic differences between the two barbells (TB and SSB).
Participants

Participant characteristics are presented in Table 1. Fifteen healthy males (average age 23.13 ± 3.93 years old) who were experienced at performing the barbell back squat, participated in this study. The average height and weight of the participants were 177.90 ± 10.18 cm and 81.64 ± 9.37 kg, respectively (table 1).

Participants met the requirements of having at least one year of experience performing the back squat with the traditional barbell (TB), with an average experience of 58.80 ± 29.93 months (table 1). There was no requirement of previous experience using the safety-squat bar (SSB), but participants had an average experience 6.00 ± 9.81 months of using the SSB (table 1). All participants were free from injuries that would have limited their ability to perform the back squat using the two different barbells. Before participation, potential participants had to sign an informed consent form (appendix 3), meet the inclusion and exclusion criteria (appendix 4) and answer no to all questions on a PAR-Q questionnaire (appendix 6). The participants were asked to refrain from any strenuous lower body activity for 72 hours before each session.

<table>
<thead>
<tr>
<th>Age (y)</th>
<th>Height (cm)</th>
<th>Mass (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>23.13 ± 3.93</td>
<td>177.90 ± 10.18</td>
<td>81.64 ± 9.37</td>
</tr>
</tbody>
</table>

Squat max and 85% of max with each barbell condition (mean ± SD)

<table>
<thead>
<tr>
<th></th>
<th>TB</th>
<th>SSB</th>
<th>TB</th>
<th>SSB</th>
</tr>
</thead>
<tbody>
<tr>
<td>100%</td>
<td>100%</td>
<td>85%*</td>
<td>85%*</td>
<td></td>
</tr>
<tr>
<td>123.17 ± 20.82</td>
<td>117.17 ± 20.82</td>
<td>104.67 ± 17.67</td>
<td>100.00 ± 15.03</td>
<td></td>
</tr>
</tbody>
</table>

* The 85% was rounded to the nearest 2.5kg
Experience performing the back squat with each barbell variation (mean $\pm$ SD)

<table>
<thead>
<tr>
<th>TB (months)</th>
<th>SSB (months)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$58.80 \pm 29.93$</td>
<td>$6.00 \pm 9.81$</td>
</tr>
</tbody>
</table>

*Table 1. Physical characteristics of the subjects (mean $\pm$ SD)*
Procedures

First testing session

During the first session, the participants signed the informed consent form and had their height and weight recorded. The participant’s quadriceps parallel squat depth was located by touching the Traditional Barbell (TB) (figure 1) or Safety-Squat bar (SSB) (figure 2) to the squat rack’s safety pins. Thereafter, a bungee cord was setup parallel to the safety pins, and then the safety pins were lowered 3 holes (7.62 cm) so the participants could touch the bungee cord in the bottom of their squat without touching the safety pins.

Figure 1. Testing at 85% of 1RM using the Traditional Barbell (TB).
Figure 2. Testing at 85% of 1RM using the Safety-Squat Bar (SSB).

As a warm-up/familiarization, the participants performed 4 sets of 10 repetitions with an unloaded barbell (SSB or TB). The barbell used was randomized for each participant but was counterbalanced so that each bar was initially used by half of the participants. During the warm-up, the participant’s squat stance was annotated (figure 3), and that same squat stance was used throughout sessions 1-3.

Figure 3. Each participant decided their own squat stance and then performed all testing with both barbells using the same stance.
After the warmup/familiarization, the participants performed a 1 repetition max (1RM) protocol with the initial barbell assigned to start. The 1RM protocol:

1x5 at 50% of estimated 1RM
1x3 at 65%
1x1 at 75%
1x1 at 85%
1x1 at 95%

Thereafter, the weight was increased between 2.5-20kg as needed until the participant was unable to complete the lift with proper form.

Up until the 85% set, the participant rested ad libitum. After the 85% set, the participants rested for 5 minutes between each set until failure was reached.

**Second session**

The second session was performed a minimum of 72 hours after the first testing session in the same location as the first session. The same warm up and 1RM protocol was performed as the first session. The barbell not tested during their first session was tested during their second session.

**Third Session**

The third session was conducted a minimum of 72 hours after the second testing session. Kinematic and kinetic data were collected for both barbell variations. The procedures occurred in the following order:

1) An updated body weight was collected.
2) Retro-reflexive markers were placed on both the left and right side of the body at the following landmarks: end of each barbell; femoral greater trochanter, anterior inferior iliac spine, lateral
and medial femoral epicondyle, lateral and medial malleolus, head of the second and fifth metatarsal and heel of the shoe. In addition, cluster sets were placed midway of the thighs and shanks.

3) Warmup (starting barbell was randomized):

1x10 with an empty barbell
1x5 at 50% of tested 1RM
1x3 at 65%
1x1 at 75%

During the warm-up, the participants rested ad libitum with a minimum of 1-minute rest between sets.

4) Data collection:

4 sets of 1 repetition at 85% (to the nearest 2.5 kg) of their 1RM for each squat variation were performed. This was done twice, for a total of 8 repetitions with each barbell.

Outline of the testing protocol (starting with the SSB):

4x1 SSB @ 85% (3 minutes rest between each set)
4x1 TB @ 85% (3 minutes rest between each set)
4x1 SSB @ 85% (3 minutes rest between each set)
4x1 TB 85% (3 minutes rest between each set)

Instruments

Every trial was filmed using a 12-camera motion capture system using Motion analysis, Raptor-E, Motion Analysis Corporation, Rohnert Park, CA, USA.

The participants were standing on one Kistler forceplate underneath their right leg (type 9287BA, Novi, MI, United States). Visual 3D (C-Motion, Inc, Germantown, MD, USA) was
used to calculate joint kinetics and kinematics for each trial. For statistical analysis, SPSS (IBM SPSS Statistics for Windows, version 26 (IBM Corp, Armonk, NY, USA) was used.
**Statistical Analysis**

Angles were calculated as the anatomical angles between two segments of the body. Peak net joint moments were calculated using standard inverse dynamic techniques. To calculate net joint moment work, the power was first calculated as the product of net joint moment and angular velocity for each joint. Then, work was calculated by integrating the power-time curve for each joint.

For the statistical analysis, a paired t-test was used to test for differences in 1-RM between bar types. A 2 x3 (bar type x joint) Factorial ANOVA with repeated measures was used to test for differences in peak flexion angles, net joint moments, and net joint moment work. Post-hoc comparisons were conducted using Fisher’s Least Significant Difference. The alpha level was set at 0.05. [The criteria for effect size were based off the paper “Determining the magnitude of treatment effects in strength training research through the use of the effect size”, by Matthew R. Rhea. This criteria is a lot stricter than the commonly used criteria for effect size being Small = > 0.2, Medium = 0.5-0.80 and Large > 0.80. Our participants fell under the “recreationally trained category (individuals training consistently from 1-5 years). This category had the following criteria for effect sizes: a Cohens d greater than: Trivial <0.35, Small = 0.35-0.8, Moderate < 0.8-1.5 and large >1.50.
Section 4: Results

The mean 1RM loads that were deployed during testing were 123.17 ± 20.82 kg for the TB and 117.17 ± 20.82 kg for the SSB. Participants could lift significantly higher loads with the TB than the SSB (P = .005; d = .858)

Joint Angles

For maximum joint angles (Figure 4), there was a significant main effect for exercise, a significant main effect for joint, and a significant interaction (all P < .001). Post-hoc analyses reveal there were no significant differences between exercises for maximum ankle angles (P = .443), but there were significant differences between exercises for maximum knee angles with TB at 115.651 ± 5.581° and SSB at 116.825 ± 5.789° (P = .011; d = .75) and maximum hip angles for the TB and SSB (129.331 ± 11.776° and 122.114 ± 12.159° P < .001; d = 1.80), respectively.

Figure 4. *Significant difference between barbell variations. Differences were considered significant when P < .05.
Joint Moments

For maximum net joint moments (Figure 5), there was a significant main effect for exercise ($P = .008$), a significant main effect for joint ($P < .001$), and a significant interaction ($P = .011$). Post-hoc analyses reveal there were no significant differences between exercises for maximum ankle net joint moments ($P = .066$) or maximum knee net joint moments ($P = .297$), but there was a significant difference between exercises for maximum hip net joint moments ($TB -2.543 \pm 0.405 \text{ N} \cdot \text{m/kg}$ and $SSB -2.403 \pm 0.363 \text{ N} \cdot \text{m/kg}$, $P = .001; d = 1.10$).

![Figure 5](image)

**Figure 5.** *Significant difference between barbell variations. Differences were considered significant when $P < .05$.

Joint Moment Work

For net joint moment work (Figure 6), there was a significant main effect for exercise ($P = .005$), a significant main effect for joint ($P < .001$), and a significant interaction ($P = .012$). Post-hoc analyses reveal there was no significant difference between exercises for the work done by the
knee net joint moments (P = .268), but there were significant differences between exercises for the work done by the ankle net joint moments (TB 0.316 ± 0.088 J/kg and SSB 0.276 ± 0.064 J/kg, P = .029; \( d = 0.63 \)) and work done by the hip net joint moments (TB 2.811 ± 0.541 J/kg and SSB 2.583 ± 0.561 J/kg, P = .002 ; \( d = .97 \)).

![Figure 6](image)

*Figure 6.* Significant difference between barbell variations. Differences were considered significant when \( P < .05 \).
Discussion

The primary objectives for this investigation were to compare the kinetic and kinematic differences between performing a parallel back squat using a Traditional Barbell or a Safety-Squat Bar while using the same foot-stance for both barbells. It was hypothesized that performing a parallel back squat with a SSB would lead to reduced forward trunk lean, increased knee moments and decreased hip moments compared to performing a parallel back squat with a TB in people experienced performing a back squat.

Results showed that the TB exercise experienced significantly higher maximum hip angle (large effect size), maximum hip net joint moment (moderate effect size), hip net moment work (moderate effect size) and maximum ankle net joint moment (small effect size), while also lifting significantly more weight than the SSB exercise (moderate effect size). The SSB exercise experienced significantly higher maximum knee angles than the TB exercise (small effect size).

In accordance with the hypothesis, the SSB had a significantly lower hip angle than the TB (large effect size), while producing significantly smaller hip maximum net joint moments (moderate effect size) and hip net joint moment work (moderate effect size) than the TB. It could be argued that the increase in maximum hip net joint moments and hip net joint moment work were due to the increased weight lifted during the TB exercise compared to the SSB exercise. However, the fact that the knee moments were slightly higher during the SSB exercise than the TB exercise indicates that the difference is due the difference in hip angles and not the increased weight lifted. Previous research shows that with a greater forward lean of the trunk, the greater the trunk extensor net joint moments were (17). Our findings support the findings of Russel et al. (17) and suggests that at the same absolute load, the TB increases the external demand on the hip extensors compared to the SSB.
Contrary to the hypothesis, there were no significant difference in knee net joint moments and knee net joint moment work between the TB and SSB. However, the SSB exercise experienced the same knee moments using a significantly lower load due to greater knee flexion angle. Previous research comparing the kinetic differences on the knee joint using different barbell position (front and back) were inconclusive in their findings (2,12,17,25). Braidot et al. (2) used the same absolute load for both front and back squat (50% of back squat 1RM), and found that the knee extensors did more work during the front squat than the back squat, indicating that the front squat might be better at increasing external demand on the knee extensors than the back squat at the same absolute load. Russel and Phillips (17) also used the same absolute load for both the front and back squat (75% of front squat 1RM) and found no significant difference in mean maximum knee extensor moments. Another study by Gullet at al. (12) used 70% of the participants’ respective 1RM for the back and front squat. The participants could lift significantly greater loads during the back squat than the front squat; and contrary to the studies that used the same absolute load (2,17), found that the back squat elicited significantly higher knee moments during the back squat than the front squat. Since the weight lifted during the back squat was significantly greater than the front squat, the increased weight might be reason for the increased knee moments during the back squat compared to the front squat. However, Wretenberg et al. (24) compared weightlifters (performing the high-bar back squat) to powerlifters (performing the low-bar back squat). They found that although the powerlifters lifted significantly greater absolute loads than the weightlifters, the weightlifters still experienced significantly greater mean maximum peak moments at the knee during the parallel squat than the powerlifters did, even though the powerlifters lifted significantly greater loads. The previous research on this area is conflicting, but our findings suggest that at lower absolute
loads, the SSB is as effective as the TB at producing similar external demands on the knee extensors.

Our research found that the ankle produced significantly higher net joint moment work with the TB than the SSB (small effect size). Braidot et al, (2) compared ankle kinetics between the front and back squat and found no difference. However, they used the same absolute load for both exercises (50% of back squat 1RM), while our participants used 85% of their respective 1RM for each barbell variation, leading to a significantly higher weight lifted during their trials with the TB compared to the SSB. This increased weight might have caused the significant increase in ankle moment work for the TB compared to SSB.

Previous research has found that an increased forward lean of the trunk increases the shear forces on the lumbar region, which could lead to increased risk for injury with heavy loads (8,10,17). It is important to note that although an increased forward lean of the trunk increases the shear forces on the lumbar region, this does not mean that it leads to injury. As with all strength training, a safe progressive program that allows your body to adapt to the external load during resistance training is important. Healthy individuals with no injuries or pain can choose freely between which exercises they prefer depending on their specific goal. However, the SSB might be a good alternative to the TB in individuals looking to maintain a more erect trunk during the squat to reduce shear forces on the lumbar region due to injury, pain etc. that gets aggravated with an increased lean of the trunk during the squat exercise.

It is worth mentioning the limitations of this body of evidence. Although something is statistically different does not necessarily mean that it will be practically different. While a one degree difference might be statistically significant, it might not have any real practical implications.
The findings that participants could lift significantly greater loads using the TB than the SSB is in accordance with previous research. Several studies have shown that squat variations that are more hip dominant, such as the back squat and low bar back squat, allow for greater loads to be lifted compared to squat variations that are less hip dominant, such as the front squat and high bar back squat (12,24,25). The reduced hip angle, decreased hip net joint moment, and hip net joint moment work experienced with the SSB compared to the TB suggests that the SSB might reduce the stress on the lower back and develop the hip extensors less than the TB.
Practical applications

This study has found that the SSB reduces the hip angles during the back squat compared to the TB. If a person wishes to maintain a more upright trunk position due to an injury/pain associated with the forward trunk lean during the traditional barbell back squat, they would be wise to try the SSB. However, if a person in healthy and wishes to lift as heavy weight as possible and/or maximize the development of the hip extensors, the TB might be a better solution, according to our research. This research concluded that there were significant biomechanical differences between the back squat between the SSB and TB. We believe that the SSB back squat is somewhere in between a TB back squat and a front squat in terms of its kinetics and kinematics. Future research should compare the biomechanical differences between the SSB back squat and a TB front squat, or compare all three (TB back squat, SSB back squat and TB front squat). Future research should also consider testing for EMG during these different squat variations.
Section 5: References


Appendix A

California State University, Northridge

CONSENT TO ACT AS A HUMAN RESEARCH PARTICIPANT

Comparison in joint angles and joint forces between the Safety-Squat Bar and Traditional Barbell back squat

You are being asked to participate in a research study. Comparison in joint angles and joint forces between the Safety-Squat Bar and Traditional Barbell back squat, a study conducted by David Johansson as part of the requirements for the M.S degree in Kinesiology/biomechanics. Participation in this study is completely voluntary. Please read the information below and ask questions about anything that you do not understand before deciding if you want to participate. A researcher listed below will be available to answer your questions.

RESEARCH TEAM

Researcher:

David Johansson

Department of Kinesiology

18111 Nordhoff St.

Northridge, CA 91330-8287

805-990-5550

David.Johansson.41@my.csun.edu

Faculty Advisor:

Sean Flanagan, PhD

Department of Kinesiology

18111 Nordhoff St.

Northridge, CA 91330-8287

818-677-7507

sean.flanagan@csun.edu

PURPOSE OF STUDY
The purpose of this research study is to investigate the difference in joint angles and joint forces between the Yoke-bar and Traditional Barbell back squat.

SUBJECTS

Inclusion Requirements

You are eligible to participate in this study if you are willing to spend 60-90 minutes on three separate occasions for information, testing and data gathering, are a male between 18-35 years old, have a minimum of one year of experience performing the barbell back squat, can perform a parallel back squat with a load at least 1 time your own bodyweight, using proper form during both the Traditional Barbell and the Safety-Squat Bar back squat, have the ability to perform a parallel back squat using maximum loading, you must be healthy and have answered no to all the questions on the modified PAR-Q (see attached), be free of any serious musculoskeletal injuries to the lower extremities in the past 6 months. A serious musculoskeletal injury is defined as one in which: a) you sought medical care b) said medical care resulted in a restriction on physical activity for longer than 2 days.

Exclusion Requirements

You will be excluded from the study if you do not have the required experience/strength when the study begins, or if you are not a male within the ages of 18-35. Additionally, you are not eligible to participate in this study if you have had any serious musculoskeletal injuries to the lower extremities in the past 6 months. A serious musculoskeletal injury is defined as one in which: a) you sought medical care b) said medical care resulted in a restriction on physical activity for longer than 2 days. You might be excluded from this study if you answer yes to one of the questions on the modified PAR-Q, unless you can provide a doctor’s note saying it is okay to participate.

Time Commitment

This study will involve approximately 3-4.5 hours of your time divided on three separate days over 1-2 weeks.

PROCEDURES

The following procedures will occur: During the first session you will sign the informed consent form and have your height and weight recorded. Thereafter you will perform a familiarization/warmup with the barbell assigned to you by performing 4 sets of 10 repetitions with 1-5 minutes of rest in between sets. Additional warmup can be performed until you feel ready to perform the exercise. Then you will perform a 1 repetition max (1RM) protocol for either the Safety-Squat Bar or the Traditional Barbell in a randomized order. After warming up with the bar you will continue the warmup by following the 1RM protocol below, you’re your estimated 1RM

1RM Protocol:
1x5 at 50%
1x3 at 65%
1x1 at 75%
1x1 at 85%
1x1 at 95%
Then the weight will increase 2.5-20kg as deemed appropriate by the Certified Strength coach until you fail with proper form within 2.5kg of a previous attempt that you made.

Up until the 85% set you will rest 1-5 minutes. After you perform the 85% set, you will rest for 3-5 minutes between each set until you reach either absolute failure (when you cannot touch the bungee cord and stand up with correct form, instead you utilize the safety/crash bars that are located 3 inches below the bungee cord to absorb the weight of the barbell and you can safely get away from the barbell, or technical failure (you touched the bungee cord and was able to stand back up again but did so with a technique deemed improper or unsafe by a certified strength and conditioning specialist).

This meeting is estimated to take 60-90 minutes and will take place in the biomechanics lab in Redwood Hall 174.

The second session will take place a minimum of 72 hours after the first testing session, same location. The same warm up and 1RM protocol will be performed as the first session. The barbell not tested during your first session will be tested during your second session. The second meeting is estimated to take 50-80 minutes.

The third session will take place a minimum of 72 hours after the second testing session. Data regarding joint angles and forces will be collected during both barbell variations. First an updated weight will be collected. Secondly a modified Helen Hayes marker set will be used to attach reflexive markers at both your left and right side of the: end of each barbell, femoral greater trochanter, anterior inferior iliac spine, lateral and medial femoral epicondyle, lateral and medial malleolus, head of the second and fifth metatarsal and heel of the shoe. In addition, cluster sets will be placed halfway down your thighs and shanks. This process requires tight fitting clothing such as short spandex, and no shirt for male participants. To locate the landmarks where to attach the reflexive markers will require the researcher to palpate your body to find the proper landmarks. This process might feel uncomfortable and can be done behind closed doors if requested. Third, the same standardized warm up will be performed as the previous two sessions. Fourth, Warmup (starting with the barbell that has been randomly assigned to the participant):

1x10 with an empty barbell (using the barbell randomly assigned to start with)
1x5 at 50% of tested 1RM
1x3 at 65%
1x1 at 75%

During the warmup you will rest 1-5 minutes. You can perform additional warmup if you need to.

Data collection:
4 sets of 1 repetition at 85% of their 1RM for each squat variation. This will be done two times for a total of 8 repetitions with each barbell.

Outline testing (starting with the SSB):
4x1 SSB @ 85% (3-5 minutes rest between each set)
4x1 BB @ 85% (3-5 minutes rest between each set)
4x1 SSB @ 85% (3-5 minutes rest between each set)
4x1 BB 85% (3-5 minutes rest between each set)
You will perform these squats while standing on force-plates. Safety bars will be set below your parallel squat depth for safety in case of a failed lift. You will rest 3-5 minutes in between each set. This third meeting is estimated to take 60-90 minutes.

**RISKS AND DISCOMFORTS**

The possible risks and/or discomforts associated with the procedures described in this study include: pain, muscle soreness, musculoskeletal injuries and skin irritation from the adhesive tape used on the markers. To minimize these risks, a standardized and thorough warm up will be conducted and you will be performing warm up sets at sub-maximal intensities to prepare yourself for heavier squatting loads. You are only allowed to participate if you are an experienced weight lifter. A Certified Strength and Conditioning Specialist will be present during all sessions to ensure that proper form is executed to minimize risk of injuries. No spotters will be used during data collection since the spotters would interfere with the motion capture cameras. Instead, safety bars will be set at a height just below your parallel squat depth to capture the bar in case of a failed lift. To prevent fatigue you will be given adequate rest, between 1-5 minutes.

You are free to stop your participation in this study at any time and for any reason. Trained CPR/AED and first aid personnel will be present during every session.

**BENEFITS**

**Subject Benefits**

You may not directly benefit from participation in this study.

**Benefits to Others or Society**

This study could help strength coaches, athletes, fitness professionals and recreational weightlifters to find an alternative squat method that might better fit certain athletes wanting to decrease the load on injured joints or target and develop certain muscles.

**ALTERNATIVES TO PARTICIPATION**

The only alternative to participation in this study is not to participate.

**COMPENSATION, COSTS AND REIMBURSEMENT**

**Compensation for Participation**

You will not be paid for your participation in this research study.

**Costs**

There is no cost to you for participation in this study.

**Reimbursement**

You will not be reimbursed for any out of pocket expenses, such as parking or transportation fees.

**WITHDRAWAL OR TERMINATION FROM THE STUDY AND CONSEQUENCES**
You are free to withdraw from this study at any time. **If you decide to withdraw from this study you should notify the research team immediately.** The research team may also end your participation in this study if you do not follow instructions, miss scheduled visits, or if your safety and welfare are at risk.

**CONFIDENTIALITY**

**Subject Identifiable Data**

All identifiable information that will be collected about you will be removed and replaced with a code. A list linking the code and your identifiable information will be kept separate from the research data. All identifiable information that will be collected about you will be shredded and removed after all data collection has concluded.

**Data Storage**

All research data will be stored on a computer, external hard drive or network that is password protected.

**Data Access**

The researcher and faculty advisor named on the first page of this form will have access to your study records. Any information derived from this research project that personally identifies you will not be voluntarily released or disclosed without your separate consent, except as specifically required by law. Publications and/or presentations that result from this study will not include identifiable information about you.

**Data Retention**

The researchers intend to keep the research data in a repository indefinitely. Other researchers will have access to the data for future research.

**Mandated Reporting** Under California law, the researcher is required to report known or reasonably suspected incidents of abuse or neglect of a child, dependent adult or elder, including, but not limited to, physical, sexual, emotional, and financial abuse or neglect. If any researcher has or is given such information, he may be required to report it to the authorities.

**IF YOU HAVE QUESTIONS**

If you have any comments, concerns, or questions regarding the conduct of this research please contact the research team listed on the first page of this form.

If you have concerns or complaints about the research study, research team, or questions about your rights as a research participant, please contact Research and Sponsored Projects, 18111 Nordhoff Street, California State University, Northridge, Northridge, CA 91330-8232, or phone 818-677-2901.

**VOLUNTARY PARTICIPATION STATEMENT**

You should not sign this form unless you have read it and been given a copy of it to keep. **Participation in this study is voluntary.** You may refuse to answer any question or discontinue your involvement at any time without penalty or loss of benefits to which you might otherwise be entitled. Your decision will
not affect your relationship with California State University, Northridge. Your signature below indicates that you have read the information in this consent form and have had a chance to ask any questions that you have about the study.

**I agree to participate in the study.**

___ I agree to be video recorded

___ I do not wish to be video recorded

___________________________________________________  ____________________
Participant Signature                                Date

___________________________________________________
Printed Name of Participant

___________________________________________________  ____________________
Researcher Signature                                Date

___________________________________________________
Printed Name of Researcher
Appendix B

Comparison in joint angles and joint forces between the Safety-Squat Bar and Traditional Barbell back squat

Questionnaire

(Please Print)

Subject Code: ________________________________________________________       Date:

Date of Birth: ____________________________       Sex: □ M □ F

Experience with Traditional Barbell Back Squat (years, months): _________________

Experience with Safety-Squat Barbell Back Squat (years, months): _________________

Have you had an injury to the lower extremity in the past 6 months?  □ Yes □ No
If yes, please describe the nature and severity of the injury or injuries:
_____________________________________________________________________________________
_____________________________________________________________________________________
_____________________________________________________________________________________

If yes, did you seek medical care for the injury or injuries?  □ Yes □ No

If you sought medical care, were you restricted from performing physical activity for more than 2 days?
□ Yes □ No

To be filled out by investigators:
Height (in): _____________       Weight (lbs): ______________

TB Back Squat 1RM (KG): ____________________       SSB 1RM (KG): ________________________
Appendix C
California State University, Northridge

VIDEO/IMAGE RELEASE FORM FOR ADULT RESEARCH PARTICIPANTS

Comparison in joint kinetics and kinematics between Safety-Squat Bar and Traditional Barbell back squat

This research project includes photographic and video images. These images are needed for research, and may include a film and/or video, motion capture, Internet web pages, or still photos. These images may be used in creative and scholarly works that may be available to the public, such as a research publication or presentation, in promotional materials, or in handouts. If you have any questions, the researcher named below will be available to answer them.

I, the undersigned participant, hereby give David Johansson specific permission to publish, copyright, distribute and/or display images (motion and still) of my likeness that have been created as part of the study referenced above under the following conditions (please provide your initials alongside each condition):

1. _______ The images can be used for scientific publications.
2. _______ The images can be shown at scientific conferences or meetings.
3. _______ The images can be shown in classrooms to students.
4. _______ The images can be shown in public presentations to non-scientific groups.

Prior to any publication, you are free to withdraw your permission to use your likeness/image at any time without penalty. If you decide to withdraw this usage, you should notify the researcher immediately.

By signing below, I acknowledge that: 1) I have read this agreement carefully; 2) any questions I have about the use of my image have been answered to my satisfaction; 3) any additional changes or restrictions that I have requested have been added in writing to this document; AND that 4) I have been given a copy of this form, including any changes or restrictions, initialed by me.

I understand and agree to the conditions outlined in this video/image release form. I have read the above information and give my consent for the use of video and/or images of me by initialing in the selected sections above.

___________________________________________________
Printed Name of Participant

Participant Signature ____________________________ Date
## Modified Physical Activity Readiness Questionnaire (PAR-Q)

<table>
<thead>
<tr>
<th>Subject Code:</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>DOB</td>
<td>Age</td>
</tr>
</tbody>
</table>

Please read each question carefully and answer every question honestly:

<p>| | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes</td>
<td>No</td>
<td>Don’t Know</td>
<td>1) Has a physician ever said you have a heart condition and you should only do physical activity recommended by a physician?</td>
</tr>
<tr>
<td>Yes</td>
<td>No</td>
<td>Don’t Know</td>
<td>2) When you do physical activity, do you feel pain in your chest?</td>
</tr>
<tr>
<td>Yes</td>
<td>No</td>
<td>Don’t Know</td>
<td>3) In the past month, have you had chest pain when you were not doing physical activity?</td>
</tr>
<tr>
<td>Yes</td>
<td>No</td>
<td>Don’t Know</td>
<td>4) Do you lose your balance because of dizziness or do you ever lose consciousness?</td>
</tr>
<tr>
<td>Yes</td>
<td>No</td>
<td>Don’t Know</td>
<td>5) Do you have a joint or bone problem that may be made worse by a change in your physical activity? If yes, explain to HPC.</td>
</tr>
<tr>
<td>Yes</td>
<td>No</td>
<td>Don’t Know</td>
<td>6) Do you currently have high blood pressure that is not controlled by medication?</td>
</tr>
<tr>
<td>Yes</td>
<td>No</td>
<td>Don’t Know</td>
<td>7) Are you pregnant?</td>
</tr>
<tr>
<td>Yes</td>
<td>No</td>
<td>Don’t</td>
<td>8) Do you have insulin-dependent diabetes?</td>
</tr>
<tr>
<td></td>
<td>Know</td>
<td></td>
<td></td>
</tr>
<tr>
<td>-------</td>
<td>------</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yes</td>
<td>No</td>
<td>Don’t Know</td>
<td></td>
</tr>
</tbody>
</table>

9) Do you know of any other reason you should not participate in physical activity?

Appendix E

Student Health Center

Location
Klotz Student Health Center
18111 Nordhoff Street
Northridge, CA 91330-8270
(818) 677-3666
shcinfo@csun.edu

Appointment and Primary Care Hours
Monday-Wednesday: 8 a.m.-5 p.m.
Thursday: 9 a.m.-5 p.m.
Friday: 8 a.m.-5 p.m.
Appendix F

Participant Information

Name___________________________  Date____________________
Subject Code____________________
Signed Adult Consent form____  Passed Study Questionnaire____
Passed PAR-Q____  Signed Video Release form____
Height______ inches
Weight_________ lbs

Session 1  Date_________  Session 2  Date_________
Barbell Variation__________  Barbell Variation__________
Squat depth__________  Squat depth__________
Stance Width:
LF_______  RF_______
LB_______  RB_______
Estimated Squat max__________ kg
Warmup (1-5 min rest)
4x10 @ empty BB _______kg
1x5 @ 50% _____kg
1x3 @ 65% _____kg
1x1 @ 75% _____kg
1x1 @ 85% _____kg (now 3-5 min rest)
1x1 @ 95% _____kg
1x1 @ ____kg
1x1 @ ____kg
1x1 @ ____kg
1x1 @ ____kg

4x10 @ empty BB _______kg
1x5 @ 50% _____kg
1x5 @ 65% _____kg
1x5 @ 75% _____kg
1x5 @ 85% _____kg (now 3-5 min rest)
1x1 @ 95% _____kg
1x1 @ ____kg
1x1 @ ____kg
1x1 @ ____kg
1x1 @ ____kg
Session 3

Name____________________ Subject Code_________________

Weight____________lbs Date____________________

Barbell Variation__________ (same as session 1)

Squat Max with this Barbell_______________ 85% = _________kg

Squat depth with this barbell_______

Stance Width:

LF________ RF_______ LB________ RB_______

Warmup (1-5 min rest)

1x10 empty barbell ________kg
1x5 @ 50% _____kg
1x3 @ 65% _____kg
1x1 @ 75% _____kg

4x1 @ 85% _____kg (now 3-5 min rest)

Change barbell to _______

Squat depth with this barbell_______

Squat max with this barbell_______ 85% = _________kg

4x1 @ 85% _____kg (3-5 min rest)

Change barbell to _______

Squat depth with this barbell_______

Squat max with this barbell_______

4x1 @ 85% _____kg (3-5 min rest)
Change barbell to ______

Squat depth with this barbell_______

Squat max with this barbell_______

4x1 @ 85% _____kg (3-5 min rest)