EXAMINING WAYS TO IMPROVE

ANKLE MOBILITY DURING THE OVERHEAD SQUAT LIFT

by

George Larson

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DURING THE OVERHEAD SQUAT LIFT

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ABSTRACT

To perform a proper squat, athletes must be mobile in the ankle, knee, and hip while maintaining a strong torso to protect the musculature surrounding the spine. Deficits in mobility, especially at the foot and ankle can cause compensation resulting in the widening of the feet and/or turning the toes outward to achieve proper squat depth. The purpose of this study is to analyze the overhead squat (OHS) in a group of female collegiate athletes and implement an appropriate ankle dorsiflexion mobility exercise program to improve squat performance. A total of 44 female student-athletes (age 18-25) were randomly divided into three treatment interventions: (1) Traditional Calf Stretch technique; (2) a joint-capsule release intervention termed "Banded Heel Cord (Anterior Bias)™"; and (3) a soft tissue intervention termed "Barbell Calf Smash™". A series of measurements were made to analyze the OHS including ankle dorsiflexion motion and movement analysis (torso angle, squat depth, shin angle, knee flare, foot width, and ankle eversion motion) at baseline and following 6 weeks of training. Analysis of covariance (ANCOVA) tests were used for comparisons between and within the three intervention groups. Improvements in DF ROM following the 6 week intervention period averaged greater than 20% in both the BHC™ and BCS™ groups; leading to significant improvements in squat depth in both groups as well. Two contemporary and novel ankle mobility exercises proved beneficial in significantly enhancing DF ROM and squat depth in our population of female student-athletes, who were considered novice to the OHS.

Keywords: strength, power, MobilityWOD™, biomechanics, dorsiflexion

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Chapter 1

INTRODUCTION

The field of Strength and Conditioning has evolved tremendously over the years to accommodate the needs of the modern athlete. Sport coaches are acknowledging the importance of year-round strength and conditioning programs for their teams. Athletes, ranging from novice to the professional level, seek sport performance specialists during their off-seasons to train and gain a competitive edge. Athletes need cardiovascular endurance, strength, power, coordination, agility, speed, flexibility, and mobility training to be successful in today's sporting endeavors. It is recognized that training these variables in a weight room or sports performance setting can lead to success in sport and injury prevention, especially in the female population.[11-14, 16-18]

The squat, no matter the variation, is a fundamental strengthening exercise we perform in everyday life that is essential to many, if not all, strength and conditioning programs working with athletes or an athletic population. To perform a proper squat, a person must be mobile in the ankle, knee, and hip while maintaining a strong torso to protect the musculature surrounding the spine. If an athlete lacks mobility and strength, they may compensate their technique and increase their risk of injury. A common compensation is to widen the feet and/or turn the toes outward to achieve proper squat depth.[1, 3, 5, 10, 22]While stance width is highly debatable, this study will look at ankle mobility and how it may be a limiting factor during the execution of the squat maneuver. Increased ankle dorsiflexion (DF) range-of-motion (ROM) leads to increased force production which can carry over to skills essential in sports requiring sprinting, cutting, and jumping.[22] Conversely, compensation of ankle DF ROM during the squat may in turn be limiting the potential for force production during many sport performance maneuvers.

Flexibility has always been an area of interest to Strength and Conditioning Specialists, with a primary focus on lengthening muscles that are short and tight. Many athletes have incorporated dynamic warm-ups or static stretching exercises to correct issues with flexibility and prepare for on-the-field sport performance. Mobility, or mobilization, is a movement-based integrated full-body approach that addresses all the elements that limit movement and performance including short and tight muscles, soft tissue restriction, joint capsule restriction, motor control problems, joint range-of-motion dysfunction, and neural dynamic issues.[22] Therefore, mobility is a tool that can be used to address issues involving poor movement and performance patterns in the athletic population. General joint mobility is important for execution in sport and training maneuvers and can involve a variety of interventions.[22] Specific to the squat maneuver, ankle DF ROM is of importance.[19] Traditional methods used to improve DF ROM have included techniques (manual or device-aided) that stretch the calf musculature. Recently, alternative techniques to improve ankle DF ROM have been introduced, however there is no evidence to support their superiority versus traditional methods. Whereas traditional techniques have focused on lengthening the calf musculature, proponents of these alternative techniques suggest that DF ROM can be enhanced by improvements in joint capsule integrity as well as improvements in soft tissue pliability.[4-6, 10, 15, 22]

A dilemma facing Strength and Conditioning Specialists each year is the arrival of an incoming recruitment class and their experience with the squat maneuver, including the Overhead Dumbbell Squat (OHS). Proper execution is especially important with the female athletic population who are at greater risk for lower extremity injury.[11, 12, 13] Therefore the purpose of this study was to analyze the OHS in a group of female collegiate athletes and implement an appropriate ankle DF mobility exercise program to improve squat performance. The study was guided by the following aims: to evaluate a group of female athletes from select sports at a large collegiate athletic program to identify which athletes can perform a proper OHS, and then to determine the effect of three different ankle mobility interventions on measures of change in squat performance and ankle DF ROM. We hypothesized that improvements in ankle DF ROM through mobility interventions would improve overall positioning of the body during the squat maneuver.

Chapter 2

SUBJECTS AND METHODS

2.1 Experimental Approach to the Problem

The study included one independent variable with 3 levels, and seven dependent variables. The independent variable in this study was the intervention effect of the Traditional Calf Stretch (TCS), Banded Heel Cord (Anterior Bias)™ (BHC™), and Barbell Calf Smash™ (BCS™) exercises. The dependent variables included: ankle DF ROM, torso angle, squat depth, shin angle, knee flare, foot width, and ankle eversion motion. A pretest-posttest randomized design was employed with subjects executing the OHS. To our knowledge, no other study has observed changes in squat position during a continuous, or multiple repetition set, making this the first functional experiment for this movement. We utilized the OHS because it forces the subjects to squat in the most upright torso position and requires sufficient ankle DF ROM to reach proper depth (femur parallel to the ground). Dumbbells were chosen to use during the OHS so as to reduce the risk of allowing the subjects to compensate their torso position by widening their hands. If the subjects attempted to widen their hands, they would drop the dumbbells and be unable to complete a successful repetition, leading us to believe that an ankle mobility issue may be the cause of the failed repetition.

2.2 Subjects

A total of 60 female student-athletes, ranging in age from 18-25 years, were recruited and randomly divided into the three treatment interventions. The student-athletes were recruited from the Tennis, Golf, and Rowing/Crew teams. All subjects signed an informed consent agreement approved by the university's IRB (451551-1) and provided preliminary demographic information (Table 1). All subjects were free from injury at the time of the study. Due to injuries sustained during their given athletic season, 16 of the participants withdrew from the study leaving 44 healthy participants for the final analysis.

2.3 Procedures

All testing occurred in a climate controlled Biomechanics Laboratory with subjects in bare feet and clothing that did not restrict movement. Dorsiflexion ROM was assessed by attaching an inclinometer to the calf while asking the subject to lunge the knee forward, keeping the heel on the ground (Figure 1). Movement (degrees) was read from the inclinometer with a single measurement derived from both ankles.

Biomechanical analysis was assessed during the execution of the OHS. Prior to performing the OHS, a set of biomechanical (adhesive reflective) markers were attached to each subject; including placement on the top of both feet in line with the 2^{nd} metatarsal, mid-tibia of each leg, on both lateral and medial malleoli of each ankle, the lateral and medial epicondyles of each knee, the greater trochanter of each femur, and on the fifth intercostal space on the right and left side of the body in-line with the marker on the greater trochanter (Figure 2). The movement (kinematic) analysis enabled for the measurements of: torso angle, squat depth, shin angle, knee flare, foot width, and ankle eversion. To ensure accuracy between pre and post-test measurements (6 weeks), each marker was measured from a specific point either on the body or between markers during the initial baseline setup. For example, the toe marker was measured as a distance (cm) from the position it was placed on the top of the foot to the end of the 2nd metatarsal. Distances were also recorded between: the medial ankle and medial knee, the lateral ankle and lateral knee, the tibial tuberosity to mid-tibia, the lateral knee and the greater trochanter, and lastly from the greater trochanter and the ribcage.

Subjects were asked to perform 5 OHS repetitions continuously while holding the dumbbells with their palms facing away (forward) from them. The subjects were instructed to squat as low as possible keeping their elbows locked out and their heels on the ground. Being novice to the OHS, no instruction was given to our subjects with regard to foot width and position, knee flare, or action of the torso. Fifteen- pound dumbbells were used by all subjects to execute the OHS. The thirty pound total weight (one dumbell/hand) is nearly equivalent to the official women's Olympic barbell of 15 kg (33 lbs). The entire baseline measurement session lasted 30 minutes.

2.3.1 Biomechanical Measurements

Torso Angle

Torso angle (degrees) was measured from the angle created between the biomechanical markers on the outside of the ribcage, the marker on the greater trochanter, and the marker on the lateral knee.

Squat Depth

Squat depth (degrees) was determined from the angle formed between the greater trochanter, the lateral femoral epicondyle, and the lateral ankle.

Shin Angle

Shin angle (degrees) was formed by the markers placed on the lateral femoral epicondyle, the lateral malleolus, and the top of the foot in line with the 2^{nd} metatarsal.

Knee Flare

Knee flare was determined by the ratio of the distance (mm) between the biomechanical markers placed on each greater trochanter, and the distance between the markers placed on each lateral epicondyle of the knee at the bottom of each squat repetition.

Foot Width

Foot width was determined from the distance (mm) between the biomechanical markers on the lateral malleoli on each ankle at the bottom position of each squat repetition.

Ankle Eversion (Foot Out-Toeing)

Ankle eversion, or the degree in which the athlete turns their feet out, was measured from the ratio of the distance (mm) between the biomechanical markers placed on the 2^{nd} metatarsals and the lateral malleoli at the bottom position of each squat repetition.

2.3.2 Interventions

Following baseline testing, the student-athletes were randomly assigned to one of three intervention groups: TCS, BHC™, or BCS™. Each intervention was carefully described and practiced on all subjects before implementation. Additionally, all exercises were performed during their scheduled team lifting session supervised by a Strength and Conditioning Specialist.

Traditional Calf Stretch (TCS)

For this intervention, these subjects placed their hands on the wall and positioned their front foot flat on the ground, far enough away from the wall that the knee could not touch the wall without the front heel elevating off the ground. The athlete then was instructed to keep the foot straight and in a subtalar neutral position, then actively flexed and extended their knee without elevating the heel off the ground to force ankle DF ROM. Additionally, the athlete actively externally rotated the knee to challenge end ROM. This stretching technique was performed in bare feet for 2 minutes on each ankle twice weekly for a total of 6 weeks (Figure 3).

Banded Heel Cord (Anterior Bias)™ (BHC™)

The subjects hooked a resistance band around a fixed object, such as a squat rack. They then placed the band at the front of the ankle at the base of the foot and created as much tension in the band as possible by pulling the foot forward. While in a lunge position with the banded foot placed forward, they placed a hand around the base of the foot to maintain a subtalar neutral position with the toes pointing forward. This allowed the subject to generate an external rotation force to stabilize the ankle in a comfortable position. The subject actively moved the knee forward, oscillating in an out of end-range ankle DF ROM keeping the heel in contact with the ground. This technique was performed in bare feet for 2 minutes on each ankle twice weekly for a total of 6 weeks (Figures 4 and 5).

Barbell Calf Smash™ (BCS™)

The subject initially placed a barbell on the ground. While seated, they placed one Achilles tendon on the barbell, crossing the other leg over to create more pressure. They actively rolled the bottom leg against the barbell from the base of the Achilles to a point just below the calf. They also continually turned their foot inward and outward to ensure they were lengthening the tissues of the lower leg at all angles. This technique was performed in bare feet for 2 minutes on each ankle twice weekly for a total of 6 weeks (Figure 6).

2.4 Post-Intervention Testing

At the conclusion of the 6 week training period, our subjects were instructed to return to the Biomechanics Laboratory for follow-up OHS biomechanical analysis. The exact procedures described above were again used at this post-intervention session.

2.5 Statistical Analysis

Statistical analysis was performed using SPSS version 20.0 software (IBM, Armonk, NY). Analysis of Covariance (ANCOVA) was utilized for comparisons between, and within, the three intervention groups (TCS, BHC™, BCS™). Separate ANCOVA tests were utilized for each of the 7 dependent variables between baseline and post-intervention measurements. Post-hoc comparisons were apportioned using Bonferroni adjustment. The significance level was set at $p \leq 0.05$ for all analyses.

Chapter 3

RESULTS

3.1 Ankle Dorsiflexion Range-of-Motion

Dorsiflexion ROM values across the three intervention groups, both pre and post-test, ranged from 25° to 57° . The results of the ANCOVA are presented separately for both the right and left ankles. There was a significant difference in DF ROM for the right ankle measurements [F (2, 40) = 7.82, p = .001]. The effect size for right ankle DF ROM was small (d = .29). Post hoc comparisons showed that the TCS group had significantly lower DF ROM values than either the BHC™ (p = .002) or the BCS™ (p = .008) groups. The BHC™ versus BCS™ comparison was not statistically significant. The right ankle showed greater improvements in DF ROM after 6 weeks of intervention training using the modern BHC™ (37.3° to 48.3° = 11° [29% improvement]) and BCS™ (39.8° to 49.4° = 9.6° [24% improvement]) interventions as opposed to the TCS (41.4° to 44.8° = 3.4° [8% improvement]) technique as compared to their baseline values (Figure 7).

There was a significant difference in DF ROM for the left ankle measurements [F (2, 40) = 4.22, p = .022]. The effect size for left ankle DF ROM was small (d = .27). Post hoc comparisons showed that the TCS group had significantly lower values than BCS group (p = .041). None of the other post hoc comparisons were significant. The left ankle showed greater improvements in DF ROM after 6 weeks of intervention training using the modern BHC™ (37.8° to 47.0° = 9.2° [24% improvement]) and BCS™ (39.9° to 48.9° = 8° [20% improvement]) interventions as opposed to the TCS (40.1° to 44.8° = 4.7° [12% improvement]) technique as compared to their baseline values (Figure 8).

3.2 Torso Angle

Torso angle values across the three intervention groups, both pre and post-test, ranged from 61.6° to 137.1°. The results of the ANCOVA showed no significant difference in torso angle measurements [F (2 ,40) = 3.15, p = .054] (Figure 9).

3.3 Squat Depth

Squat depth values across the three intervention groups, both pre and post-test, ranged from 54.4° to 120.1°. The results of the ANCOVA demonstrated significant differences in squat depth measurements [F (2, 40) = 7.77, p = .001]. The effect size for squat depth was small (d = .22). Post hoc comparisons showed that the TCS group had significantly greater squat depth values than either the BHC™ (p = .032) or the BCS™ (p = .001) groups. The BHC™ versus BCS™ comparsion was not statistically significant. Greater improvements in squat depth after 6 weeks of intervention training occurred in both the modern BHC™ (92.5° to 84.7° = 7.8° [8%improvement]) and BCS™ (91.5° to 81.0° = 10.5° [11% improvement]) interventions as opposed to the TCS (89.9° to 88.3° = 1.6° [2%improvement]) technique as compared to their baseline values (Figure 10).

3.4 Shin Angle

Shin angle values across the three intervention groups, both pre and post-test, ranged from 54.2° to 87.0°. The results of the ANCOVA showed no significant difference in torso angle measurements [F (2, 40) = 0.71, p = .499] (Figure 11).

3.5 Knee Flare

Knee flare ratio values across the three intervention groups, both pre and post-test, ranged from 1.09 to 2.14. The results of the ANCOVA showed no significant difference in knee flare ratio measurements [F (2 ,40) = 1.97, p = .153] (Figure 12).

3.6 Foot Width

Foot width values (cm) across the three intervention groups, both pre and post-test, ranged from 392.0 to 809.7. The results of the ANCOVA showed no significant difference in foot width value measurements [F (2, 40) = .073, p = .488] (Figure 13).

3.7 Ankle Eversion

Ankle eversion ratio values across the three intervention groups, both pre and post-test, ranged from 0.90 to 1.36. The results of the ANCOVA showed no significant difference in ankle eversion ratio measurements [F (2, 40) = 1.06, p = .357] (Figure 14).

Chapter 4

DISCUSSION

Strength and Conditioning Specialists have long relied on the execution of the squat maneuver to aid in improving athletic performance. This study involved an examination of increasing ankle DF ROM and observing if such an improvement leads to better overall positioning during the OHS maneuver. The most significant finding of this study was that increased ankle DF ROM did, in fact, lead to better positioning during the OHS. The use of two unique and contemporary exercises for improving DF ROM in our cohort of female athletes proved to be very beneficial in bringing about this change. Additionally, our methodology for analyzing the OHS allowed us to efficiently evaluate the squat maneuver and use it as a tool to track changes in OHS performance after the intervention period had concluded.

Improvements in DF ROM following the 6 week intervention period averaged greater than 20% in both the BHC™ and BCS™ groups. Interestingly, and although not significant, there were improvements of up to 12% in the control group subjects performing traditional DF flexibility exercises. Both the BHC™ and BCS™ training groups performed a unique set of exercises aimed at improving DF ROM. The BHC™ exercise involved a self-administered joint mobilization activity intended to improve ankle (talocrural) joint function. Traditionally, such ankle joint mobilizations have been restricted to relieving pain and improving ROM in injured joints.[9] To our knowledge, this is the first study that has involved such techniques in an uninjured population. Deficits in DF ROM have been related to restricted posterior glide of the talus on the tibia.[7] Joint mobilizations, especially those involving anterior to posterior gliding of the talus on the tibia, have been shown to be effective in improving ankle DF ROM.[23] The self-administered BHC™ intervention proved to be beneficial in improving DF ROM in our cohort of subjects and involved an anterior to posterior glide maneuver. Starrett has referred to this phenomenon as “clearing adhesions from the joint” to improve DF ROM.[22] Likewise, DF ROM improvements were evident in the BCS™ intervention group. This exercise involved a hybrid myofascial release technique using a self-administered “calf smash” against a barbell. Myofascial pain in the calf muscles has been documented to cause biomechanical abnormalities, especially with gait.[24] Additionally, taut bands on skeletal muscle and fascia can cause stiffness and restricted ROM even in the absence of pain.[21] Simons et al. used the terminology “trigger point pressure release” as a myofascial technique that lengthens sarcomeres and was effective in increasing ROM and reducing muscle tension.[20,21] Subsequently, from a strength and conditioning perspective this is a soft tissue modality that can be easily adopted. One of the benefits to a Strength and Conditioning Specialist is that both of these effective DF ROM “self-administered” interventions require very little time and effort on the part of the coach.

In executing the OHS, squat depth is a vital component. Depending on philosophical viewpoint, proper squat depth has included the idea of femur parallel to the ground, hamstring parallel to the ground, or quadriceps parallel to the ground. In the present study, our biomechanical analysis of squat depth focused on the femur being parallel to the ground. Squat depth relies heavily on the ability of the athlete to achieve maximum dorsiflexion in the ankle joint; otherwise compensations will occur at other joints along the kinetic chain. We contend that the improvements seen in ankle DF ROM, as a result of the BHC™ and BCS™ interventions, likely transferred to the improvements in squat depth in both of these groups as well. Strengthening our argument involving improved DF ROM translating into enhanced squat depth is the fact that none of the other squat performance variables were impacted as a result. In other words, we improved OHS performance without imparting changes in other aspects critical to proper squat execution. With regard to shin angle, some would argue that the enhanced squat depth could have been a result of changes in shin angle but that was not the case in our study. We are confident that the lack of change involving torso angle, shin angle, knee flare, foot width, and ankle eversion suggest that the DF ROM improvements favorably impacted squat depth at no expense to the other biomechanical variables measured.

While we are optimistic about the results of our investigation, we would like to acknowledge the following limitations. Our study cohort consisted of female athletes from three select sports, and although we purport that our changes could take place in other female student-athlete populations we were restricted to these three sports. Additionally, we did not control for the time period in each female student-athlete's monthly menstrual cycle. There is some evidence that suggests that ankle laxity is not affected, and as a result, we decided not to monitor this potential limitation.[2, 8] Lastly, the *a priori* power analysis calculations suggested that approximately 20 subjects per intervention group would sufficiently power our study. Due to unexpected injuries during the course of the study period, we suffered some attrition in each group; however we are confident based on our *post-hoc* effect size calculations that the limited attrition did not greatly impact our results.

Educating student-athletes on the proper execution of the OHS, or any squat variation, is a vital component of the performance enhancement process. Moving forward, it would appear logical that the next potential study would be to monitor to see whether or not the improvements in DF ROM and subsequent changes in squat depth are maintained over longer periods (one year, playing career, etc…). Although our primary focus was on the female student-athlete cohort, we recommend that future studies involving the male counterparts be undertaken. With past evidence targeting hip mobility and improved squat performance, it would also be interesting to do a comparative study examining hip versus ankle mobility interventions.

Practical Application

Based on the results of the present study, two contemporary and novel ankle mobility exercises proved beneficial in significantly enhancing DF ROM and squat depth in our population of female student-athletes, who were considered novice to the OHS. The ankle mobility exercises are safe, effective, and easy to implement into a strength training regime without much effort on the part of the Strength and Conditioning Specialist. Despite our use of advanced biomechanical analysis equipment, we contend that even a simple video tape analysis of the OHS, along with the easy DF ROM measurement technique, that the majority of Strength and Conditioning Specialists could employ such measurements.

Chapter 5

TABLES AND FIGURES

Table 1: Participant demographics (Mean ± SD).

Characteristic	Group		
	TCS (N = 14)	BHC™ (N=16)	BCS™ (N=14)
Age (years)	19.4 ± 1.2	19.4 ± 0.8	19.4 ± 1.2
Mass (kg)	62.3 ± 10.6	64.2 ± 10.7	63.4 ± 9.6
Height (cm)	166.0 ± 8.50	168.0 ± 8.50	166.0 ± 6.10

Figure 1: Range-of-motion using a bubble inclinometer.

Figure 2a: Side view of biomechanical marker placement for all subjects.

Figure 2b: Front view of biomechanical marker placement.

Figure 3a: Traditional Calf Stretch (TCS) starting position with the front foot forward in a subtalar neutral position.

Figure 3b: Keeping the front heel in contact with the ground and the foot in a subtalar neutral position, drive the knee towards the wall forcing ankle dorsiflexion. Oscillate between the starting position and the forced ankle DF position to try to improve ROM.

Figure 4a: Lateral view of the Banded Heel Cord (BHC ™)start position. Place the band at the front of the ankle at the base of the foot and use you hand to maintain subtalar neutral position with a vertical shin.

Figure 4b: Keep the heel in contact with the ground and maintain a neutral foot position. Drive the knee forward generating external rotational force at the ankle to ensure stability. Oscillate (rock back and forth) from start to finish positioning to challenge end ROM.

Figure 5a: Anterior view of proper Banded Heel Cord (BHC™) starting position.

Figure 5b: Anterior view of the proper end position; maintaining a subtalar neutral positioning of the foot while driving the knee forward and outward.

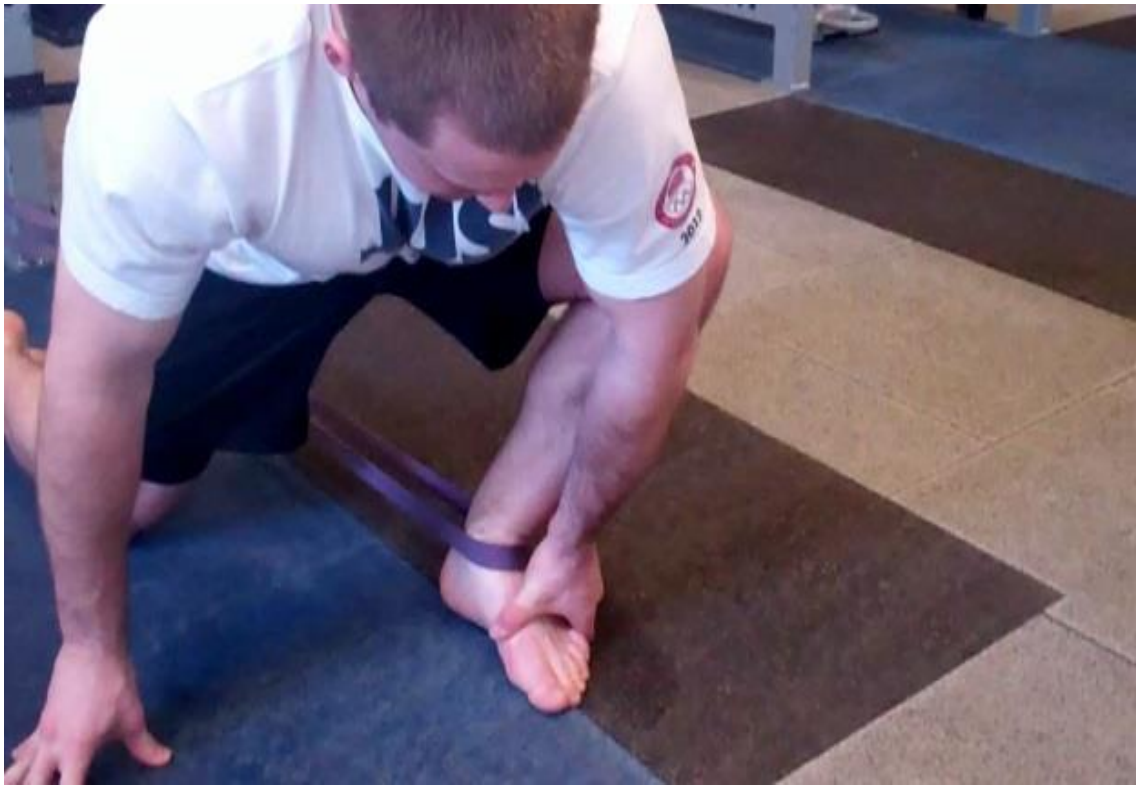


Figure 6a: Starting position for the Barbell Calf Smash (BCS™) with the barbell placed on the Achilles and the top foot applying pressure onto the bottom foot.

Figure 6b: End position for the BCS™ at the bottom of the calf. Actively roll the barbell between the start and ending position.

Figure 7: Right Ankle DF ROM between the TCS, BHC™, and BCS™ intervention groups. Note: * indicates significance between baseline and final measurement.

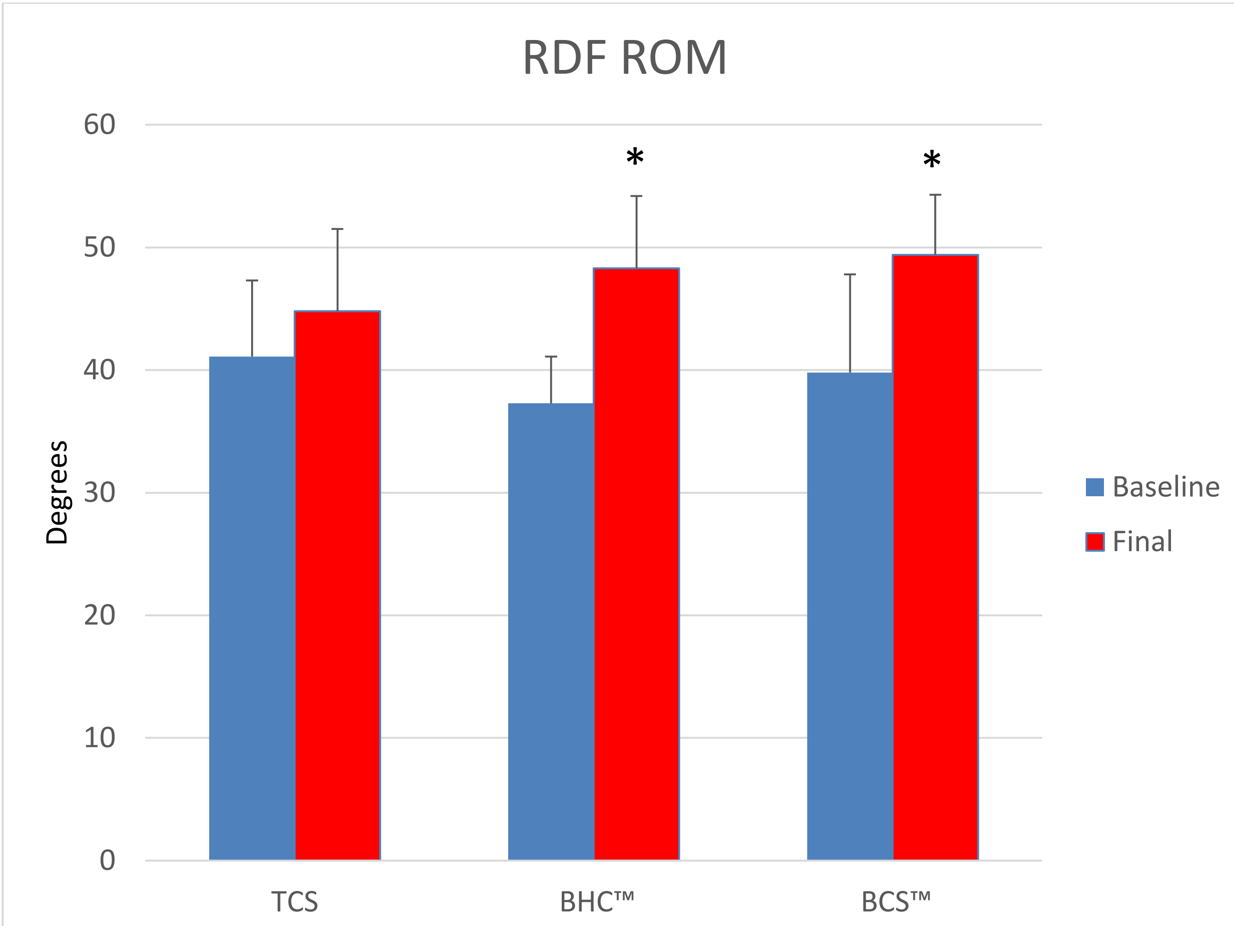


Figure 8: Left Ankle DF ROM between the TCS, BHC™, and BCS™ intervention groups. Note: * indicates significance between baseline and final testing measurement.

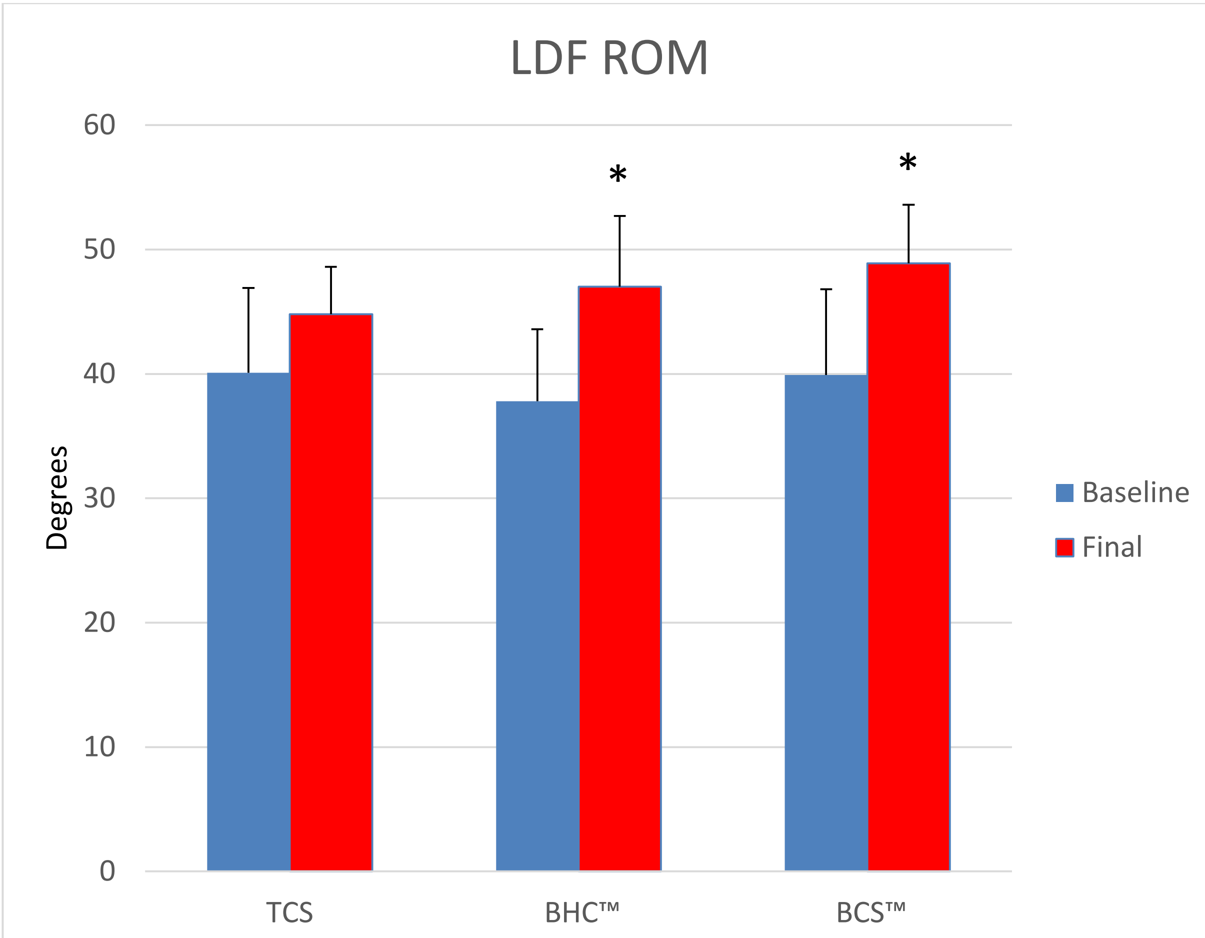


Figure 9: Torso Angle between the TCS, BHC™, and BCS™ intervention groups.

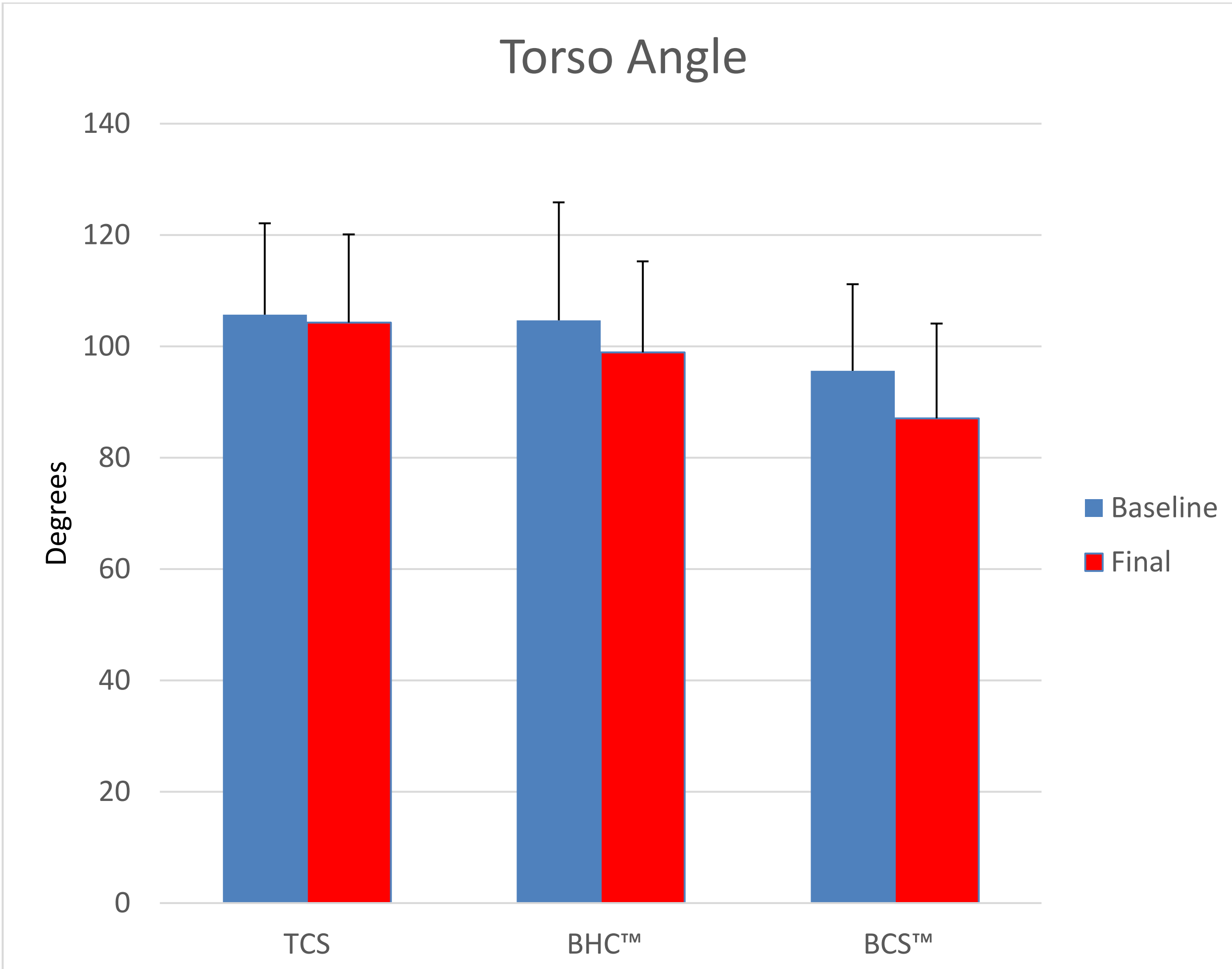


Figure 10: Squat Depth between the TCS, BHC™, and BCS™ intervention groups. Note that * indicates significance between baseline and final measurement.

Figure 11: Shin Angle between the TCS, BHC™, and BCS™ intervention groups.

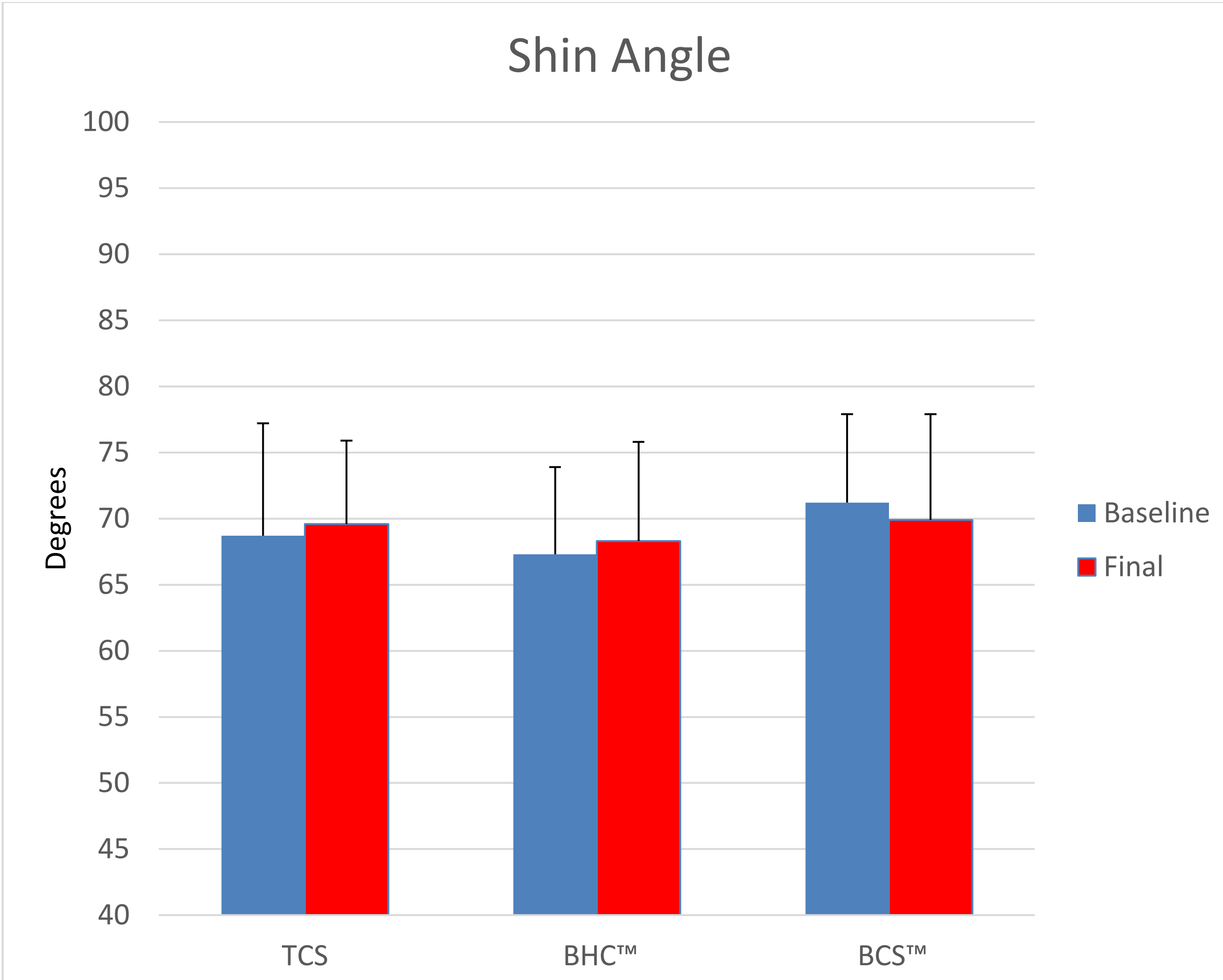


Figure 12: Knee Flare between the TCS, BHC™, and BCS™ intervention groups.

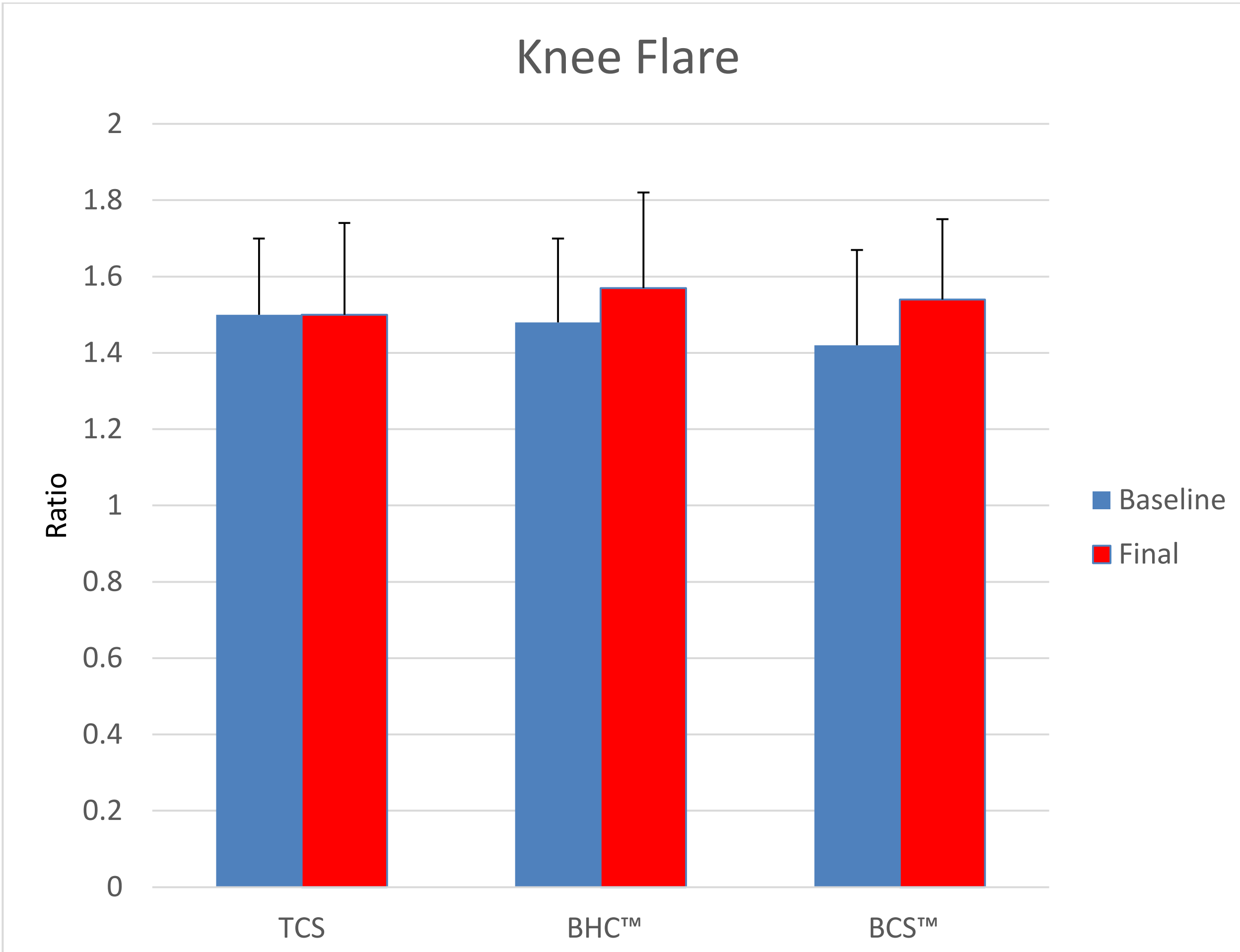


Figure 13: Foot Width distance (mm) between the TCS, BHC™, and BCS™ intervention groups.

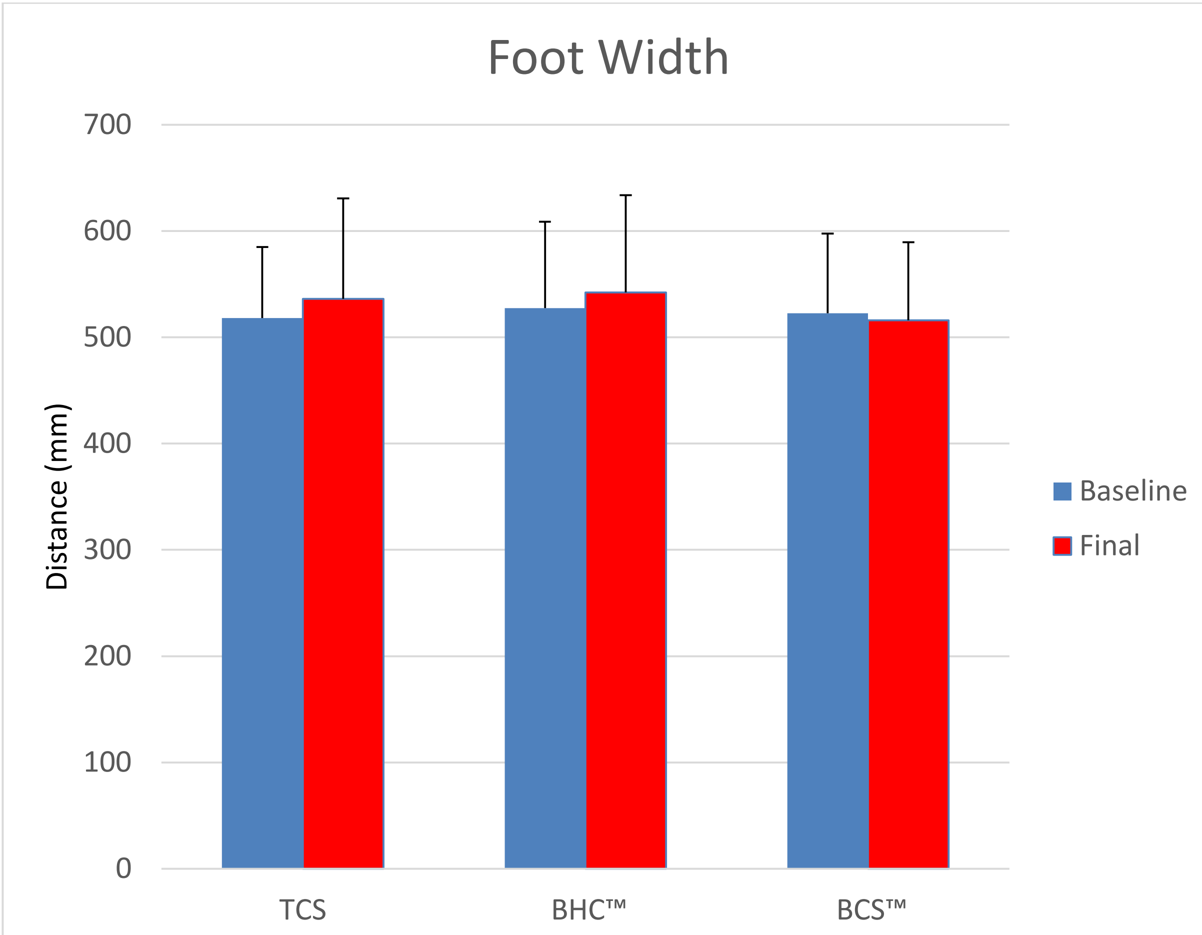
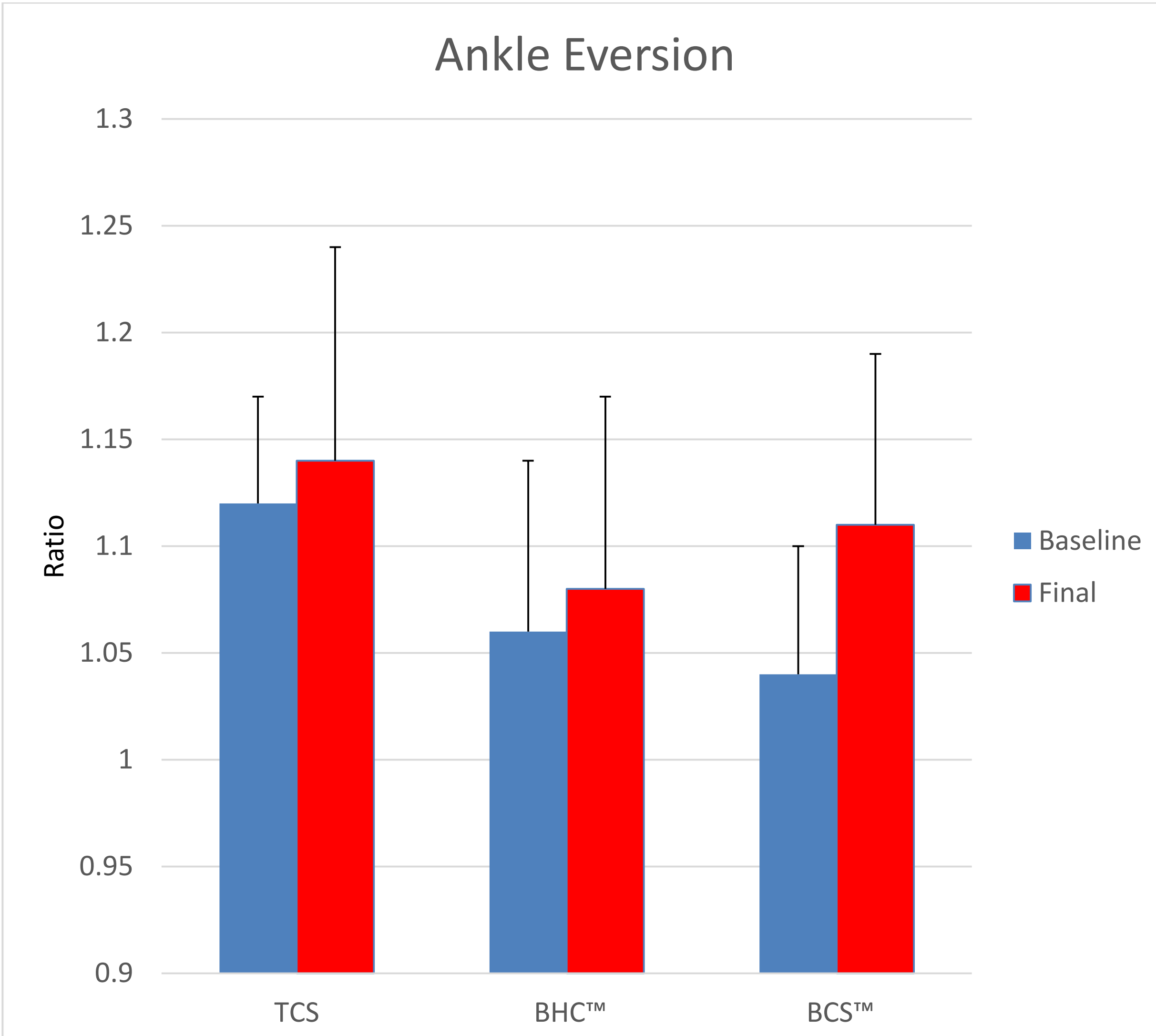


Figure 14: Ankle Eversion between the TCS, BHC™, and BCS™ intervention groups.



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Appendix A

INFORMED CONSENT FORM

University of Delaware
Informed Consent Form

Title of Project: Examining Ways to Improve Ankle Mobility during the Overhead Squat Lift

Principal Investigator (s): George “Packer” Larson

Other Investigators: Thomas Kaminski, Jaclyn Caccese

You are being asked to participate in a research study. This form tells you about the study including its purpose, what you will do if you decide to participate, and any risks and benefits of being in the study. Please read the information below and ask the research team questions about anything you do not understand before you decide whether to participate. Your participation is voluntary and you can refuse to participate or withdraw at anytime without penalty or loss of benefits to which you are otherwise entitled. If you decide to participate, you will be asked to sign this form and a copy will be given to you to keep for your reference.

WHAT IS THE PURPOSE OF THIS STUDY?

The squat exercise is an important part of athletic performance. The purpose of this study is to compare the effects of three different ankle stretching exercises on execution of the Overhead Dumbbell Squat (OHS) exercise. You are being asked to take part in this study because you are currently free from injury and may partake in regular strength training, practice, and/or game activities relative to your sport. You will be one of 60 female student-athletes from the University of Delaware between the ages of 18-25 participating.

WHAT WILL YOU BE ASKED TO DO?

All testing will be performed in the biomechanics lab on the second floor of the Fred Rust Ice Arena at the University of Delaware. The information gathered in this study will be used for George “Packer” Larson’s (Principal Investigator) thesis. The study is voluntary and requires 3 days of testing (30-minutes each) over 6 weeks. After signing this consent form, we will take initial measures of ankle dorsiflexion (DF) range-of-motion (ROM) and a movement analysis of the OHS.

<u>Measurements</u>

Your ankle ***range-of-motion*** will be assessed by attaching an inclinometer (using Velcro) to your calf while asking you to lunge your knee forward. (Figure 1)

Figure 1: Range-of-motion using a bubble inclinomter

Participant Initials ________

University of Delaware
Parental Consent Form

Title of Project: Investigation of Cerebral Blood Flow in Healthy and Concussed Athletes

Principal Investigator: Jaclyn B. Caccese

Advisors: Dr. Thomas W. Kaminski, Dr. Andrew Reisman, Dr. Geoffrey Gustavsen

Your child is being asked to participate in a research study. This form tells you about the study including its purpose, what your child will do if he/she decides to participate, and any risks and benefits of being in the study. Please read the information below and ask the research team questions about anything we have not made clear before you decide whether your child may participate. Your child's participation is voluntary and he/she can refuse to participate or withdraw at anytime without penalty or loss of benefits to which he/she is otherwise entitled. If your child decides to participate, you will be asked to sign this form and a copy will be given to you to keep for your reference.

WHAT IS THE PURPOSE OF THIS STUDY?

The primary purpose of this study is to determine the effects of concussions on cerebral blood flow (blood flow to the brain) across age ranges, and to compare these effects to differences seen in neurocognitive testing. A secondary purpose of this study is to determine the effects of a season of playing a sport, including potentially sub concussive blows, on cerebral blood flow.

To measure cerebral blood flow, quantitatively, we will use the Brain Acoustic Monitor. The Brain Acoustic Monitor (BAM) is an investigational device created by Active Signal Technologies that measures blood flow to the brain non-invasively (no skin will be broken; the two sensors look and feel like a stethoscope). Cerebral blood flow is changed when a person experiences mild traumatic brain injury, such as a concussion. By measuring cerebral blood flow at baseline (before the start of a season) and post-concussion, we can determine the effects that a concussion has on cerebral blood flow. Additionally, by taking measures at the end of a season, and comparing these measures to the baseline measurements, we can determine the effects of a season of playing a sport on cerebral blood flow. Finally, by including high school and collegiate athletes, we can determine the differences in how cerebral blood flow is affected across age ranges.

As an investigational device, one aim of this investigation is to test the BAM in a population of athletes with sports-related concussions. The data collected on both concussed and non-concussed athletes will be shared with Arthur Cooke at Active Signal Technologies to improve sensitivity and specificity of the BAM.

Participant Initials ________

Next, we will conduct a ***movement analysis*** of you performing an OHS using two 15 lb. dumbbells (Figure 2). Adhesive markers will be placed on various landmarks over your lower body to enable us to measure OHS performance (Figure 3). You will be asked to complete a series of OHS repetitions for one minute.

Figure 2: Overhead Dumbbell Squat

Figure 3 a-b: Anterior (**a**) and Lateral (**b**) views of the biomechanical marker placement

<u>**Group Assignments**</u>

You will be randomly assigned to one of three ankle stretching groups.

Traditional Calf Mobilization Group

The exercise (Figures 4 and 5), is a traditional stretching activity used to improve ankle DF ROM. You will perform this exercise barefooted for a total of 2 minutes on each ankle. You will perform this exercise twice weekly for 6 weeks. This exercise will be performed in addition to others assigned as part of your normal training routines supervised by UD's Strength and Conditioning staff.

Figure 4: Starting position with the front foot forward in a subtalar neutral position.

Figure 5: Keeping the front heel in contact with the ground and the foot in a subtalar neutral position, drive the knee towards the wall forcing ankle dorsiflexion. Oscillate (rock back and forth) between the starting position and the forced ankle dorsiflexion position to try to improve ROM.

Participant Initials ________

Data obtained in this investigation may be used in the thesis and dissertation of Jaclyn B. Caccese, principal investigator.

Your child is being asked to take part in this study because your child is a student-athlete from a high school near the University of Delaware.

This study will be done over a three-year span, but your child will only be asked to participate for one season. Three hundred student-athletes from the University of Delaware will be invited to participate in this study.

Nine hundred student-athletes from surrounding high schools, including: St. Mark's High School, A.I. DuPont High School, Wilmington Friends School, Tower Hill School, Charter School of Wilmington, and Newark High School will be invited to participate in this study.

Student-athletes will be recruited from the UD intercollegiate D1 teams, including: football, men's soccer, women's soccer, and men's lacrosse, and from UD intercollegiate club teams, including: men's soccer, women's soccer, men's lacrosse, men's ice hockey, and women's ice hockey teams. Members of these teams will be recruited because of the head-contact nature of their sport. Additionally thirty UD intercollegiate club men's cross country or UD intercollegiate D1 women's cross country runners will be invited to participate.

Interscholastic student-athletes invited to participate will be members of the football, boy's soccer, girl's soccer, ice hockey, or boy's lacrosse teams. Again, members of these teams have been selected because of the head-contact nature of their sport. Additionally, fifty boy's and girl's cross country student-athletes will be invited to participate from these schools.

Cross country student-athletes who participate in this investigation may not participate in any head-contact sports during the season. Additionally, cross country athletes included must have no previous history of concussion.

Your child *should not participate* in this investigation if he/she is currently exhibiting symptoms of a concussion (i.e. headache or a feeling of pressure in the head, temporary loss of consciousness, confusion or feeling as if in a fog, amnesia surrounding the traumatic event, dizziness or "seeing stars", ringing in the ears, nausea or vomiting, or slurred speech) or if a physician as has diagnosed him/her as concussed and he/she is currently unable to participate in his/her sport. If you sustain a concussion during the season that requires an over-night hospital stay, you will be excluded from post-concussion measurements.

WHAT WILL YOU BE ASKED TO DO?

Your child will be asked to report to the athletic training room at your child's high school for BAM, King-Devick, and BESS tests. ImPACT testing may be done in a computer lab at your child's high school or in the athletic training room, if necessary.

Participant Initials ________

Banded Heel Cord (Anterior Bias)™ Group

The exercise (Figures 6-8), demonstrates one hybrid stretching activity used to improve ankle DF ROM. You will perform this barefooted for 2 minutes on each ankle. You will perform this exercise twice weekly for 6 weeks. This exercise will be performed in addition to others assigned as part of your normal training routines supervised by UD's Strength and Conditioning staff.

Figure 6 a-b: Lateral view of the start position. Place the band at the front of the ankle at the base of the foot and use you hand to maintain subtalar neutral position with a vertical shin (**a**). Keep the heel in contact with the ground and maintain a neutral foot position. Drive the knee forward generating external rotational force at the ankle to ensure stability. Oscillate (rock back and forth) from start to finish positioning to challenge end ROM (**b**).

Figure 7 a-b: Anterior view of proper starting position (**a**). Anterior view of the proper end position; maintaining a subtalar neutral positioning of the foot while driving the knee forward and outward (**b**).

Figure 8: Improper end positioning of the intervention with the heel coming off the ground.

Barbell Calf Smash™ Group

The exercise (Figures 9 and 10), demonstrates another hybrid stretching activity used to improve ankle DF ROM. The subject will perform this barefooted for 2 minutes on each ankle. You will perform this exercise twice weekly for 6 weeks. This exercise will be performed in addition to others assigned as part of your normal training routines supervised by UD's Strength and Conditioning staff.

Figure 9: Starting position for the Barbell Calf Smash™ with the barbell placed on the Achilles and the top foot applying pressure onto the bottom foot.

Figure 10: End position for the Barbell Calf Smash™ at the bottom of the calf. Actively roll the barbell between the start and ending position.

Follow-up Measurements

At the conclusion of weeks 3 and 6 of training, you will be instructed to return to the biomechanics lab to perform the exact ROM and movement analysis measurements described above. At the conclusion of follow-up testing after week 6, you will no longer be part of the study, but will continue with your normal training activities as prescribed and supervised by UD's Strength and Conditioning staff.

WHAT ARE THE POSSIBLE RISKS AND DISCOMFORTS?

There are no risks above and beyond what you normally would experience during a supervised training session with UD athletics. In the event that you are injured while enrolled in the study, first aid treatment will be provided by the University of Delaware Athletic Training staff.

WHAT ARE THE POTENTIAL BENEFITS?

While participating in this study, you may benefit from improved ankle DF ROM that will promote increased performance of the OHS in the weight room; which in turn could improve your sport performance.

HOW WILL CONFIDENTIALITY BE MAINTAINED?

If you choose to participate in this study, you can be assured your information is kept confidential. For this study, you will be identified only by your subject number. Records of this information will be kept on electronic file, available only to those directly associated with the research. This consent form will be the only document with your name and personal information. This consent form and data collected will be stored for three years. The consent form will be locked in a file cabinet in the Athletic Training Research Lab (Room 160 of the Human Performance Laboratory). No personal information will be shared when the results of this study are reported.

Your research records may be viewed by the University of Delaware Institutional Review Board, but the confidentiality of your records will be protected to the extent permitted by law.

WILL THERE BE ANY COSTS RELATED TO THE RESEARCH?

There will be no cost to you for participating in the study.

WILL THERE BE ANY COMPENSATION FOR PARTICIPATION?

There will be no financial compensation for completion of this study.

WHAT IF YOU ARE INJURED BECAUSE OF THE STUDY?

If you are injured during research procedures, you will be offered first aid at no cost by the University of Delaware Athletic Training staff. I f you require additional medical treatment, you will be responsible for the cost.

DO YOU HAVE TO TAKE PART IN THIS STUDY?

Taking part in this research study is entirely voluntary. You do not have to participate in this research. If you choose to take part, you have the right to stop at any time. If you decide not to participate or if you decide to stop taking part in the research at a later date, there will be no penalty or loss of benefits to which you are otherwise entitled. Your refusal will not influence current or future relationships with the University of Delaware.

As a student-athlete, if you decide not to take part in this research, your choice will have no consequence on your academic status, your grade in class, and WILL NOT affect your playing status on your respective team. Your participation may be terminated by investigators if you are not cooperating with the instructions given. You have the right to cease participation at any time during the study.

WHO SHOULD YOU CALL IF YOU HAVE QUESTIONS OR CONCERNS?

If you have any questions about this study, please contact the Principal Investigator, George "Packer" Larson at 302-598-2487 or the Advisor, Thomas W. Kaminski at 302-831-6402.

If you have any questions or concerns about your rights as a research participant, you may contact the University of Delaware Institutional Review Board at 302-831-2137.

Participant Initials ________

Your signature below indicates that you are agreeing to take part in this research study. You have been informed about the study's purpose, procedures, possible risks and benefits. You have been given the opportunity to ask questions about the research and those questions have been answered. You will be given a copy of this consent form to keep.

By signing this consent form, you indicate that you voluntarily agree to participate in this study.

_________________________________ _____________

Signature of Participant Date

____

Printed Name of Participant

_________________________________ _____________

Signature of Principle Investigator Date

____

Printed Name of Principle Investigator

Participant Initials ________

Appendix B

DATA COLLECTION SHEET

Subject Number: ___________

Intervention Group: _________

University of Delaware AT Research Lab

Data Collection Form

Title of Project: Examining Ways to Improve Ankle Mobility during the Overhead Squat Lift

Name:____ Sport:___________________ Gender:____________

Height:____________________ Weight:_________________ Age:__________ DOB:_______________________

E-mail address:______________________________________ Cell Phone:_________________________________

Measures

Ankle DF ROM:

R:______________________________ **L:**__________________________________

Right Side Electrode Placement:

Dist between lat ankle and knee:________________

Dist between lat knee and GT:__________________

Dist between GT and Ribcage:__________________

Dist from tibial tuberosity to shin:______________

Dist between med ankle and knee:______________

Dist from toe to toe marker:___________________

Left Side Electrode Placement:

Dist between lat ankle and knee:________________

Dist between lat knee and GT:__________________

Dist between GT and Ribcage:__________________

Dist from tibial tuberosity to shin:______________

Dist between med ankle and knee:______________

Dist from toe to toe marker:___________________

FINAL DF ROM:

R:_________________________________

FINAL DF ROM:

L:_________________________________

Appendix C

SPECIFIC AIMS

The field of Strength and Conditioning has evolved tremendously over the years to accommodate the needs of the modern athlete. Sport coaches are acknowledging the importance of year-round strength and conditioning programs for their teams. Athletes, ranging from novice to the professional level, seek sport performance specialists during their off-seasons to train and gain a competitive edge. Athletes need cardiovascular, strength, power, coordination, agility, speed, flexibility, and mobility training to be successful in today's sporting endeavors. It is recognized that training these variables in a weight room or sports performance setting can lead to success in sport and injury prevention, especially in the female population.[35,35,38,41, 43, 44,52]

The squat, no matter the variation, is a fundamental strengthening exercise we perform in everyday life that is essential to many, if not all, Strength and Conditioning programs working with athletes or an athletic population. To perform a proper squat, a person must be mobile in the ankle, knee, and hip while maintaining a strong torso to protect the musculature surrounding the spine. If an athlete lacks mobility and strength, they may compensate their technique and increase their risk of injury. A common compensation is to widen the feet and/or turn the toes outward to achieve proper squat depth.[4, 13, 19, 33, 58] While stance width is highly debatable, this study will look at ankle mobility and how it may be a limiting factor during the execution of the squat maneuver. Increased ankle dorsiflexion (DF) range-of-motion (ROM) leads to increased force production which can carry over to skills essential in sports requiring sprinting, cutting, and jumping.[58] Compensation of ankle DF ROM during the squat may in turn be limiting the potential for force production during many sport performance maneuvers.

Flexibility has always been an area of interest to Strength and Conditioning and Sports Performance Specialists. Flexibility focuses on lengthening muscles that are short and tight. To correct this issue, many athletes have performed dynamic warm-ups or static stretching exercises to correct issues with flexibility and prepare for on-the-field sport performance. Mobility, or mobilization, is "a movement-based integrated full-body approach that addresses all the elements that limit movement and performance including short and tight muscles, soft tissue restriction, joint capsule restriction, motor control problems, joint range-of-motion dysfunction, and neural dynamic issues."[58] Therefore, mobility is a tool used to address issues with poor movement and performance patterns in the athletic population. General joint mobility is important for execution in sport and training maneuvers.[58] There are a variety of methods used to improve joint mobility. Specific to the squat maneuver, ankle DF ROM is of extreme importance.[55] Traditionally, Strength and Conditioning Specialists would try to improve dorsiflexion ROM with ways, or devices, that stretch the calf musculature i.e. slant boards, etc... Recently, some specialists have explored alternative techniques to improve ankle DF ROM; however, no studies have attempted to explore which method is superior.

Utilizing a large collegiate female student-athlete population, Overhead Dumbbell Squat (OHS) performance will be carefully examined, and those unable to properly execute the movement will be identified. Therefore the purpose of this study is to analyze the OH Squat in a group of female collegiate athletes and implement an appropriate ankle dorsiflexion mobility exercise program to increase squat performance.

The following aims will guide this research effort:

Specific Aim 1: To evaluate a group of female athletes from select sports at the University of Delaware to identify which athletes can perform a proper OHS.

Hypothesis 1: We anticipate an overwhelming majority (greater than 75%) of these female athletes will be identified as having improper squatting technique, thus creating the participants for this intervention study. Studies have shown that the ability to correctly perform a proper squat for a trained athlete is low[17, 50, 58], and considering the OHS is the most difficult squat variation[55], we anticipate the majority of our subjects to have poor technique in the OHS.

Specific Aim 2: We intend to determine the effect of three different ankle mobility interventions on measures of change in squat performance and ankle dorsiflexion ROM.

Hypothesis 2.1: Athletes in each of the 3 mobility intervention groups will show improvement in squat performance and ankle dorsiflexion ROM.[4, 31, 33, 51, 55]

Hypothesis 2.2: Although we anticipate all three interventions will positively impact squat performance, subjects assigned to the modern MobilityWOD™ interventions will demonstrate superior performance in the depth of the OHS as measured by an increase in getting to or below thigh parallel to the ground.

Hypothesis 2.3: Athletes performing the MobilityWOD™ interventions will demonstrate an increase in torso angle while performing the OHS.

Hypothesis 2.4: Athletes performing the MobilityWOD™ interventions will demonstrate a decrease in shin angle while performing the OHS.

Hypothesis 2.5: Athletes performing the MobilityWOD™ interventions will demonstrate a decrease in foot width positioning during the OHS.

Hypothesis 2.6: Athletes performing the MobilityWOD™ interventions will demonstrate a decrease in "out-toeing" (ankle eversion/tibial external rotation) while performing the OHS.

Hypothesis 2.7: Athletes performing the MobilityWOD™ interventions will demonstrate an increase in repetitions completed in a minute, and a greater time to failure while performing the OHS.

Appendix D

BACKGROUND AND SIGNIFICANCE

D.1 Background

To understand the importance of the squat exercise, we must understand the history of weight-lifting. The genealogy of lifting traces back to the beginning of recorded history where man's fascination with physical prowess can be found among numerous ancient writings.[1] The earliest reference to formal strength training occurs in Chinese texts dating back as far as 3600BC. when emperors made their subjects exercise daily and potential soldiers had to pass weight-lifting tests before being allowed to enter the armed forces.[63] There has also been much evidence of weight-training used in ancient Egypt and India, while the Greeks left numerous sculptures of their athletes training with weights. [63] The 6th century BC was known as the 'Age of Strength' and weight-lifting competitions involved lifting heavy stones. [63] Weight training was not confined to men: a wall mosaic from a Roman villa in Piazza Almeria in Sicily depicted a girl exercising with weights. [63] While weight-lifting has its origins dating so far back, the science and expansion of the sport was never deeply studied until around the 16th century. From that time on, the emergence of books about weight-training began to explode from all around the world, most notably in England, France, and Russia. [63] The first modern day Olympics were held in 1896 and weightlifting was included as an official sport.[1] As weight-lifting emerged as an Olympic sport, the 1900's saw an explosion in the popularity of weight-training and competitions in basic feats of strength. With this comes the origin and popularity of the squat exercise in sport.

While the basic movement of the squat maneuver can be traced back thousands of years, the popularity of the squat can be pin-pointed to the date October 21, 1921. A young German immigrant, Henry Steinborn, set a world record by squatting a 402lb. barbell.[60] Steinborn did not do this conventionally. A barbell was loaded with 402lb. on the ground and Steinborn upended the barbell, leaning to one side and placing his hands on it slightly beyond shoulder width. He then squatted down, allowing the barbell to rock across his shoulders, and stood up with the weight then reversed the process after squatting the weight for many repetitions.[60] This single event propelled the squatting exercise to become relevant in sport not only in America, but worldwide. [60] In the 1930's, 40's, and 50's, Olympic lifters, such as 1956 American Olympic weight-lifting gold medalist Paul Anderson, began utilizing the squat in their training protocols.[54] The squat as an exercise began to gain popularity as a lift in strongman competition, and in 1972 an International Powerlifting Federation (IPF) set the squat as one of the three movements an athlete will perform to compete in what is now known as the sport of Powerlifting.[62] Today, Powerlifting is a recognized sport that tests athletes in the Bench Press, Deadlift, and Squat. While all three of these lifts are utilized in modern Strength and Conditioning Programs, the Squat is the exercise that defines lower body strength.[59]

D.2 Significance – The Squat and How it Applies to Modern Sport and Strength and Conditioning Programs

The bilateral squat is one of the most prevalent exercises used in strength training world-wide.[18] It is a fundamental movement pattern that requires mobility at the ankle, hip and thoracic spine and stability at the foot, knee, and lumbar spine.[42] The popularity of the squat is certainly a reflection of its practicality. Humans throughout time have used variations of the squat pattern to accomplish various tasks associated with activities of daily living.[2, 14] A significant amount of research has been dedicated to establish the resisted squat as an effective exercise for enhancing strength and power performances[4, 11, 22, 23, 25, 26, 30] ,which makes it one of the most widely used exercises for increasing physical strength and power.[4] The effects of the squat are easily reflected in the most basic sport movement of sprinting. This interest is a result of the defined relationship between the ability to apply force into the ground to increase running velocity.[64, 65, 66] Several investigators have found a strong correlation between ground reaction force (GRF) or impulse magnitude and sprinting velocity.[37, 65]

Several investigations have shown the relationship between GRF capabilities and sprinting performance.[37, 64, 65] In addition Weyand et al., reported that maximal sprinting velocity was a product of GRF and not the leg speed of runners; in fact swing time (stride frequency) for the legs of slow and fast runners was identical at approximately 0.360 seconds.[65] Hunter et al. has reported a significant correlation between GRF horizontal impulse and sprinting velocity.[37] Therefore, it is evident that strength or maximal force production is an essential component to maximal sprinting velocity.

Given the known relationship between GRF and sprinting velocity and the contribution from the major muscle groups of the lower body, it has been shown that the squat strengthens the proper lower body musculature to apply a greater GRF. A study by McBride et al.[47] reported that both 10 and 40 yard sprint times increased when an athlete could squat greater than 2.1 times their body weight when compared to those who could only squat 1.9 times their body weight. This finding is consistent with previous studies, Wisloff et al.[66], that showed improved 10 yard sprint times in athletes who could squat more weight. In summary, it appears that horizontal ground reaction force, net GRF, and net impulse all demonstrate strong correlations with sprinting velocity whereas leg speed is not a factor in increased sprinting velocity.[46, 47, 64, 65] Thus, one of the primary factors determining sprinting velocity is the ability to generate large GRF with the lower-body musculature, making this area an obvious site of interest for maximizing sprinting ability. It can be speculated then that a focus of resistance training on increasing lower-body structural multiple-joint movements of strength (i.e., free weight squat) compared to single leg movements is warranted.

Despite the stereotype, the squat exercise is not just reserved for male athletes. Although American women first began strength training for sports in the 1950s to improve their performance in track and field, they have traditionally participated in strength training less than men.[24] Such exercise has not been considered feminine, and a lack of research and information regarding the effects of training on women has made it a predominantly male activity. Women's participation was particularly limited until 1972, when Title IX mandated equal access to educational programs--including athletics--for men and women in schools that receive federal funding.[24] Since then, women's sports participation has exploded, traditional gender roles have loosened, and strength training has grown in popularity among active women. Since the advent of Title IX, according to the National Federation of State High School Associations, the number of girls playing high school sports has grown more than tenfold, from 294,000 in 1971 to nearly 3.2 million in 2012.[24] There has been an equal growth in the female sport participation in the collegiate level during this time frame. In 2002, the number of female athletes competing in collegiate athletics was reported to be 158,469.[8] The number of female athletes reported in 2011 was reported to be 191,131.[8] The biggest difference a female athlete will encounter in the transition between high school and college athletics is the incorporation of a strength and conditioning program as a year-round training.[9]

Like their male counterparts, girls have started to specialize early in their careers, working on just one sport year-round, often as a way to capture the attention of college coaches. With more scholarship money available than ever, girls feel pressured to specialize at a young age in the hopes of winning a spot on an elite team or gaining an edge in the increasingly competitive college admissions game. Despite persistent warnings from orthopedic surgeons and athletic trainers, young athletes bent on specialization continue to suffer from preventable overuse injuries (tendonitis bursitis, stress fractures, etc…).[12] According to the American College of Sports Medicine, 50 percent of these overuse injuries are preventable.[12] Additionally, of special concern for female athletes is damage to the anterior cruciate ligament (ACL), as they are four to five times more likely than their male counterparts to suffer injury to this structure. Compounding matters is that once girls begin to menstruate, they also develop a tendency to utilize their quadriceps muscle more than their hamstrings, making them more vulnerable to ACL injury. This is turn enables female athletes to jump and land in a more erect posture, further stressing the ACL.[29] Therefore, as Strength and Conditioning Specialists, getting female athletes to utilize proper running, jumping, and landing techniques is apparent in an attempt to prevent injury. One such exercise at the core of each of these sport movements is the squat.

D.3 Significance - Execution of the Squat

There are many variations of the squat technique, including stance width, foot positioning, and squat depth. However, previous research has indicated that the optimal squat technique is a wide stance(≥ shoulder width) with natural foot positioning, unrestricted movement of the knees, and full depth (femur parallel to the floor) while the lordotic curve of the lumbar spine is maintained with a forward or upward gaze.[18]

D.3.1 *Stance Variation*

In a narrow stance squat, the mechanical demand is distributed across the hip and knee extensors and ankle plantar-flexors.[25] As the stance width increases, the demand placed on the ankle plantar-flexors decreases and the demand placed on the hip and knee extensors increases.[25] With extremely wide stance widths, it is possible that the ankle dorsiflexors are required. Squats that do not allow the knees to move forward (ankle dorsiflexion) result in greater forward trunk lean[30], which increases loading of the lumbar spine.[10] Therefore, the decision to use one technique versus another cannot simply be made by considering which technique allows the most weight to be lifted.

D.3.2 *Sitting Back*

Sitting back into the squat, also known as the hip hinge by McGill[49], should be used to initiate the eccentric portion of the lift. Sitting back allows the gluteus maximus, a powerful hip extensor, to immediately become a part of the lift, particularly increasing activation in a deeper squat. Without this posterior shift, the squat exercise will emphasize the quadriceps; deemphasizing the gluteus maximus throughout the lift. Research shows that sitting back and preventing the knees from moving too far beyond the toes does increase hip torque.[30] Sitting back to minimize anterior translation of the knees will also decrease torque at the knee joints.[30, 45] The quadriceps are still a major component of the lift, but now, the gluteal muscles can share the load more evenly distributing forces throughout the lower extremities. For those with knee pain, this can make an immediate difference in their ability to perform the lift. For athletes without current knee issues, it can be a way to avoid future problems because of overloading.[15] To achieve a parallel squat or deeper, the knees will travel past the toes to a degree, but it should be clear that ‘‘sitting back’’ is not a way of preventing this but rather limiting excessive anterior shift of the tibia at the knee.[15]

Engaging the gluteal muscles by sitting back also has the effect of preventing excessive lumbar lordosis, a common cause of spondylolytic disorders.[15] The gluteus maximus has the ability to resist excessive anterior tilting of the pelvis because it offsets the pull of the lumbar paraspinals, to keep the lumbar spine in a neutral position.[15] The ability to maintain a neutral lumbar spine throughout the lift has been shown to increase stability through the spine, allowing it the ability to bear greater compressive loads, and reduces shear forces.[32] Another biomechanical advantage of sitting back is to reduce the ankle dorsiflexion moment; in other words maintaining a vertical shin angle. As the knees travel past the toes, dorsiflexion requirements become greater. An athlete with ''stiff ankles'' will do one of three things: (a) the heels could come off the floor and increase shear forces at the knee[45] (b) the heels come off the floor causing the athlete to lose balance, and (c) excessive subtalar pronation occurs along with femoral internal rotation with the result being unacceptable valgus at the knees.[15] The combination of increased knee valgus and anterior tibial shear forces has also been shown to increase stress on the anterior cruciate ligament.[45] Teaching athletes to sit back to initiate the squat can have several important benefits, including a more even distribution of load between the hip and knee extensors, maintaining a neutral spine, keeping the heels on the floor, and preventing valgus collapse of the knees. Each of these can lead to a safer and more effective squat during training and potentially lead to greater athletic performance.

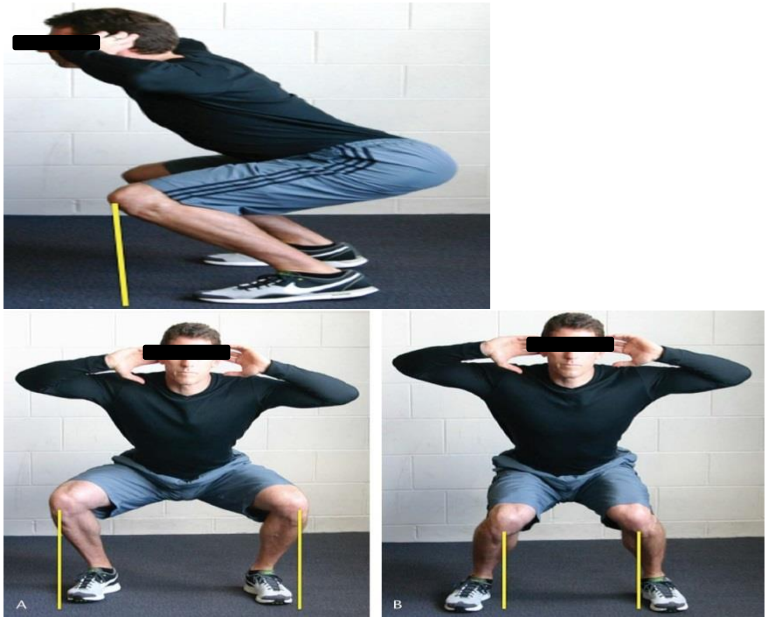

Figure 1 a-c: A squat maneuver with excessive forward motion of the knees in front of the toes. (**a**) A squat maneuver with proper knee positioning outside of the feet. (**b**) A squat maneuver with valgus collapse of the knees (**c**).[42]

Figure 1 presented above depicts different positions of the knee joint during a squat maneuver. National Strength and Conditioning Association (NSCA) guidelines recommend the knee should not travel anterior to the toe.[20] Reasons for this are: (a) an emphasis on loading the hip extensor muscles (gluteals) and (b) protection of the knee joint from excessive flexion.[20] While ‘‘sitting back’’ may be effective for some athletes, it has important drawbacks to consider. ‘‘Sitting back’’ places the hip joint further behind the feet, moving the body’s center of mass posteriorly, and maintaining weight over the feet requires some form of compensation to prevent falling backward.[15] This is usually accomplished by anterior lean of the trunk, ideally from increased hip flexion while maintaining a neutral spine. However, this requires adequate hip ROM as well as back extensor strength and spinal stability. Otherwise, an athlete must flex the spine to maintain balance, presenting well-documented risks that contradict accepted squatting guidelines.[20, 49] Harvey et al.[34] has shown that restricted anterior movement of the knees during squatting increased loads at the hip but also caused excessive forward lean of the trunk and was likely to inappropriately transfer load to the lower back. Although reduced knee flexion is proposed to decrease stress in the knee, it may also compound risk to the spine by limiting hip ROM afforded by the 2-joint hamstring muscles.[15] Thus, in an attempt to protect the knee, ''sitting back'' may pose additional risk to the spine.

Recent evidence also suggests that excess flexion can aggravate hip joint pathology in some athletes.[45] The major determinant of lower extremity joint loads during the squat is the location of the GRF. Especially with higher barbell loads, GRF location is driven primarily by the position of the upper body because it has the greatest mass.[15] Whether one ''sits back'' or not, forward lean of the trunk and/or greater barbell mass places greater relative demand on the hip joint.[32, 34] The difference is that ''sitting back'' requires this forward lean to maintain stability. If instead the knees are allowed to remain at or even beyond the toes, a greater range of trunk position is possible. Forward lean can be allowed if hip ROM and back strength permit. Alternatively, a more erect position can be maintained while still keeping weight over the feet. Shifting weight forward has the added benefit of increasing torque at the ankle joint, providing greater training stimulus to the plantar flexors.[32] A more anterior knee position usually implies greater ankle dorsiflexion and knee flexion, which are often said to pose a risk to the knee. Evidence to date however suggests that thigh-parallel squats are safe for healthy athletes, although deeper squatting might pose additional risk to the knee menisci or ligaments (principally the posterior cruciate ligament).[30] In the presence of a knee injury, reduced barbell loads and/or limited squat depth to control knee flexion are better options than a strategy that could pose undue risk to the spine.[15] Many athletes that have restrictions in DF ROM are asked to ‘‘sit back,’’ causing similar concerns related to torso angle. Corrective measures could include mobility/flexibility training, limitation of squat depth, changes in barbell load, and/or elevating the heels.[13]

D.3.3 *Muscle Activation*

There is continued debate among strength and conditioning experts regarding the most appropriate foot placement and squat depth, not only in terms of stresses on the knee but also in terms of recruitment of muscles. Electromyographic studies have found that increased squat depth (half squat 45°, parallel squat 90°, full-depth squat 125°) resulted in a greater percentage contribution of the gluteus maximus during the full-depth squat.[11, 53] During the eccentric phase of the weighted-back squat, the relative contributions of 4 muscle groups (vastus medialis, vastus lateralis, biceps femoris, gluteus maximus) at the 3 depths tested were not statistically different.[11] Therefore, muscle activation did not differ based on squat depth. However, it is important to mention loads used were submaximally (25% body weight and 100–125% body weight) and recruitment patterns may change at near-maximal loads.[11]

Rotating the feet (neutral, 30–40°medial, 80° lateral rotation) while performing the squat, regardless of depth and stance width (75–140% shoulder width), has been shown to have no noticeable effect on muscle activity of the lower leg (rectus femoris, vastus medialis, vastus lateralis, adductor longus, semimembranosus, semitendinosus, and biceps femoris).[27, 28, 48, 53, 56] Two studies indicate stance width variation does alter muscle recruitment patterns by increasing activity of the adductor longus when a wide stance is used (> shoulder width).[48, 53] However, rotating the feet outward may place greater demands on the ligaments of the knee .[58] When there is a lack of DF ROM, there is a tendency to lack the ability to drive the weight up through the heels. An athlete will anteriorly displace the weight to the toes which can cause an anterior shift during the movement and increase rotational torque at the knee.[19]

D.4 Significance - Forces Placed on the Knee

A study calculating forces during the squat movement reported patello-femoral joint (PFJ) forces during the ascent phase of a deep squat regardless of the speed were present (reference). Another study determined that PFJ forces increase with greater amounts of knee flexion during the squat maneuver.[18] Research has also demonstrated increases in tibio-femoral joint (TFJ) forces during the squat and leg press when there was a greater amount of knee flexion.[27] It has also been shown that the squat exercise produces significantly less anterior displacement when compared to the open kinetic chain exercise of leg extension, producing less strain on the anterior cruciate ligament (ACL).[6, 28, 39] Similar results regarding peak posterior cruciate ligament (PCL) forces have also been reported, where forces >4.5 times body mass during isokinetic and isometric leg extension, compared with 3.5 times body mass during the squat.[28, 61] This suggests that the squat may result in a lower risk of injury than a simple leg extension exercise. However, it is worth mentioning that PCL forces increase with increased knee flexion, or depth, during the squat.[57, 68] Despite this increase, the PCL can sustain much greater forces to failure than the ACL. Other research has found that the ACL was subject to small forces during the squat when the knee was less than 50° of flexion and when the angles increased, the PCL rather than the ACL receive greater loads.[27, 61] ACL forces were also much lower when the squat was performed with heals on the ground compared with when the squat was performed with heels elevated during both the descent and the ascent phases.[61] Therefore, it is important to gain ankle dorsiflexion ROM so we may perform a squat with our heels on the ground rather than displacing the weight towards our toes to lessen the forces placed on the knee.

D.5 Significance - Assumptions on How to Squat

Table 1

	Downward and upward movement phases of a bilateral body weight squat			
Anatomical region	Baechle [5]	Bloomfield [7]	Kinakin [40]	Summary
Head	Neutral position	Held up	Neutral position	Neutral
Thoracic spine	Flat: maintain torso to floor angle	Angled slight forward and held straight	Flat: maintain torso and shin angle	Slightly extended
Lumbar spine	Flat: maintain torso to floor angle	Curved slightly inward	Flat: maintain torso to shin angle	Neutral
Hip joints	Flexed	Flexed	Flexed: remain under the shoulders	Flexed and aligned
Knees	Flexed: knees aligned over the feet	Flexed	Flexed: knees over the feet	Aligned with feet
Feet/ankles	Shoulder width/remain on the floor	Shoulder width, toes pointing forward	Shoulder width stance	Flat not rolling in or lifting up

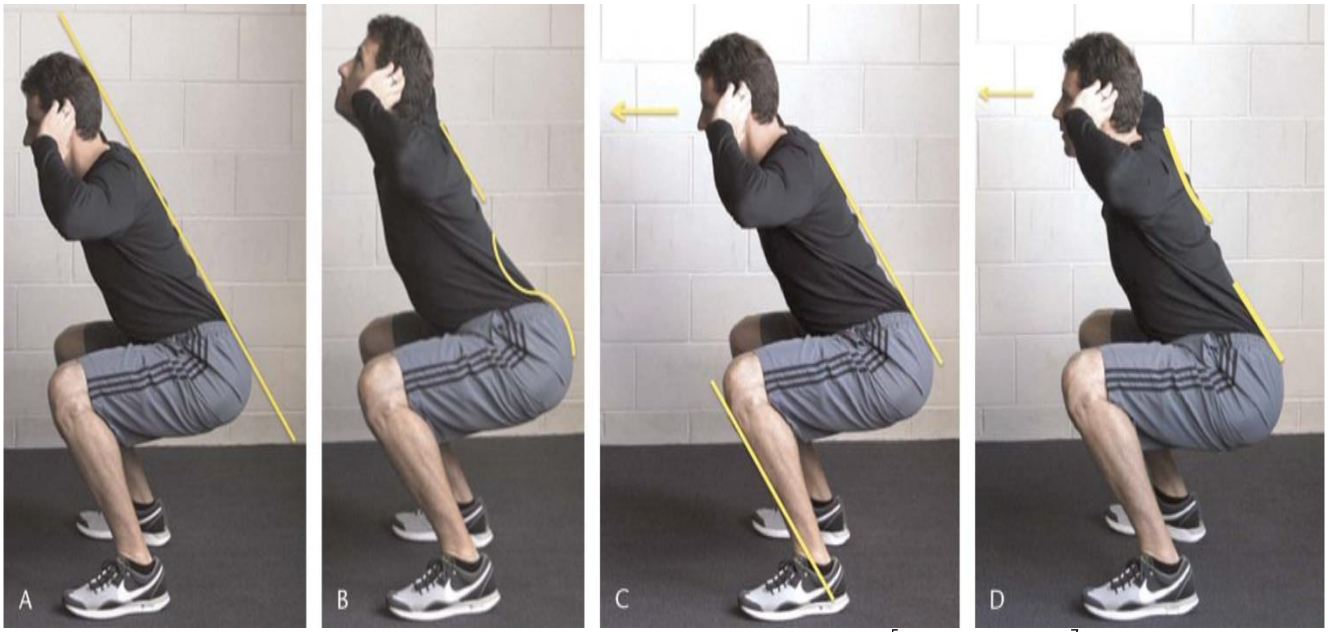

Figure 2 a-d: A graphic depiction of the criteria detailed in Table 1: (**a**) Baechle[5]; (**b**) Bloomfield[7]; (**c**) Kinakin[40]; and (**d**) summary.[42]

Table 2

Downward and upward movement phase of a bilateral bodyweight squat pattern			
Anatomical region	Optimal viewing position	Faulty pattern	Optimal pattern
Head	Side, front	Movement of the head too far forward or back, movement of the head to either side. Direction of gaze is below a neutral position.	Held straight inline with the shoulders, gaze straight or slightly up.
Thoracic spine	Side, back	Abducted scapulae and flexion or excessive extension of the thoracic spine.	Scapulae adducted, slightly extended or neutral and held stable.
Lumbar spine	Side	Extension or flexion prior to movement, unstable, extension or flexion at any time during the movement.	Neutral, stable throughout movement.
Hip joints	Front, side	Mediolateral rotation, lateral dropping.	Stable, no mediolateral movement and no dropping of the hips, should stay aligned with knees.
Knees	Front, side	Alignment inside or outside the hip. Medial collapse and / or excessive forward movement in front of the toes.	Aligned with the hips and feet, stable, no excessive movement inside or out, forward or back.
Feet/ankles	Front, side, back	Pronation or supination of the feet, and/ or heels lifting off the ground at any time during the movement.	Feet flat and stable, heels in contact with the ground at all times.

Tables 1 and 2 presented above provide suggestions for optimal patterns of the squat maneuver.[42] Of special concern is the ideal positioning of the knees and the feet. The knees should be aligned with the hips and feet, stable, with no excessive movement inside or out, forward or back; the feet should be flat and stable, heels in contact with the ground at all times.[42] These established guidelines are of concern especially with relation to the knees being in line with the feet and the feet being flat to the ground. Defining how to keep the feet flat is of concern based on the way most people have evolved in their foot positioning. The intent of this project is to look closer at this concept in the squat maneuver. Keeping the knees in line with the feet may allow an athlete to track their knees over their toes, placing unwanted forces through the knee joint, and minimizing the optimal amount of torque their body is naturally made to create.

D.6 Significance - Contemporary Concepts on Squat Execution

In his recently published book, "*Becoming a Supple Leopard*", Dr. Kelly Starrett has introduced his concepts on human movement patterns. He devoted an entire chapter of his book to the squat maneuver. Within that chapter, Dr. Starrett lists common movement compensations, gives reasons as to why those compensations occur, and provides corrective exercises in an attempt to improve those compensations. The following sections provide his concepts on squat execution.

D.6.1 *Hip Mobility and the Squat*

When observing an athlete performing a squat, it's important to look at torso position, hip mobility, knee position, and ankle mobility.[58] Deficits in the squat maneuver are often associated with lack of mobility in the ankle and hip.[58] Deficits in hip mobility are typically associated with deficits in internal hip rotation, thus allowing the knees to collapse inward.[58] Additionally, we compensate by leaning the trunk forward, rounding the truck, or overextending the trunk.[58] These compensations may lead to an increase in a back injury by placing unnecessary forces on the vertebrae.[58] Therefore, closely examining hip mobility deficiencies within the squat maneuver is of concern.

D.6.2 *Neutral Spine and the Squat*

Neutral spine is a term synonymous with "setting the core". To obtain a neutral spine, athletes are told to squeeze the gluteal muscles together, bringing the pelvis and hips closer to the femur.[58] Furthermore, athletes are instructed to squeeze the ribcage downward in an attempt to anchor it toward the hips.[58] These two techniques when combined allow an athlete to brace their core and keep it in a neutral position. This position prevents the athlete from overextending or rounding their back, protecting the spine.

D.6.3 *Ankle Mobility and the Squat*

Modern footwear has an elevated heel, resulting in a restriction of the heel cord and reflecting in poor ankle dorsiflexion ROM.[58] This restriction has led to calf stiffness and the turning out of the toes during the squat maneuver.[58] Many athletes have to turn their feet out dramatically in order to achieve full depth during the squat. [58] While this is clearly functional, it's not optimal. In fact, when the feet turn out past 15 degrees, it can result in poor motor control, deficits in internal hip rotation, a tight anterior chain (quads, etc.), and stiff ankles. [58] The further out the feet go, the less effective the hip rotators are at resisting the valgus forces at the knee created by the body. [58] Somewhere between 5-12 degrees appears to be an area where an athlete can achieve proper depth and create optimal amounts of torque throughout the squat. [58] Athletes will turn out their feet in order to "*un-impinge*" the hip. [58] While this mechanically "*un-impinges*" the hip, the mechanical advantage of being in a stable position is lost, making it harder to keep the knees out without allowing them to track over the foot. [58] Tracking the knee outside the feet creates a stable knee position, while positioning the knee over the feet creates an unstable knee position. [58]

The modern elevated shoe heel has also led to navicular drop. [58] The medial malleolus starts to drop inward from a flat foot position which causes tibial torsion. [58] When there is navicular drop, there is a collapse in the whole kinetic chain. Internal tibial torsion puts the knee in a valgus position. [58] Valgus positioning puts heavy strain on the ACL. When the feet turn out, in addition to navicular drop, there is increased potential exposure of the knee to a valgus position because there is a decreased ability to flare the knees outside of the toes when squatting, increasing the chance to collapse the knee during the movement. [58] Therefore when squatting, a subtalar neutral position with the feet straight should be considered optimal so there is a reduced chance to collapse the knee when squatting; thus reducing the chances of valgus positioning of the knee.[58] Default motor planning (i.e. poor mechanics) will translate to movement in sport (running, landing, jumping).[58] When the knees come in front of the toes, there is an increased load on the anterior chain of the leg which places more force on the knee.[58] When the feet turn out, the knee joint position is considered open.[58] The popliteus muscle closes the knee joint position which protects athletes from MCL and ACL injuries when jumping and landing.[58] With valgus positioning, the patellar tracking is disrupted leading to patella femoral pain.[58] This valgus position is seen especially in young female athletes.[35,35,38,41, 43, 44,52 ,58] Therefore it is important to make sure the ankle does not collapse and translate up the kinetic resulting in compensations for hip internal rotation and an open knee valgus position.

Increasing ankle DF ROM allows an athlete to achieve greater squat depth, and also enables the athlete to flare the knees and open the hips to create more torque and less tension in those joints.[58] Many experts blame hip ROM for defects in squatting, but when there are improvements in hip ROM and athletes still collapse at the bottom of the squat, Strength and Conditioning Specialists need to look for other causes and the ankle joint may be one aspect to consider.[58] Improving ankle joint capsule ROM may allow athletes to flare the knees thus creating an ability to improve squat positioning at the bottom of the movement.[58] This in turn keeps the knees from tracking over the toes lessening the forces on the knee and enabling the athlete to create the greatest amount of torque to execute the squat maneuver.[58] Flaring the knees out also makes the hips more stable and a stable hip creates a more upright torso and decreases forces placed on the spine.[58]

Traditional coaching cues have taught athletes to push the hips back then descend into a squat. Pushing the hips too far back will force the spine to hyperextend. Therefore when performing a squat an athlete should: brace their core to keep the spine neutral, screw their feet into the ground to achieve a subtalar neutral position, and descend with the hips moving back and the knees flaring out simultaneously.[58] The feet should be as neutral as possible to decrease forces placed on the knee.

D.7 Significance - Flexibility vs. Mobility

The terms flexibility and mobility are often used interchangeably by the general population.[58] Often, clinicians will also use these terms to refer to the same thing. This, however, is incorrect. Flexibility and mobility are related, but they are different. Stretching to improve flexibility only focuses on lengthening short and tight muscles. Mobilization, on the other hand, is a movement-based integrated full-body approach that addresses all the elements that limit movement and performance including short and tight muscles, soft tissue restriction, joint capsule restriction, motor control problems, joint range-of-motion dysfunction, and neural dynamic issues.[58] In short, mobilization is a tool to globally address movement and performance problems. Mobility should be a proactive approach, not a reactive one. In other words, don’t wait until problems arise before you address them.[58] Mobility can be broken down into three primary modalities: soft tissue focus, stretching, and joint mobilization.

D.7.1 *Soft Tissue*

There are a number of modalities within the soft tissue focus. Self-myofascial release (SMFR) is the most common form of soft tissue interventions.[58] Tools such as foam rollers, massage sticks, Thera Cane® (Thera Cane Central), and lacrosse balls are common tools for this modality. SMFR can be performed before or after training sessions. Sometimes SMFR alone isn't enough and an athlete will have to seek out other sports healthcare professional trained to deal with issues outside the scope of a fitness coach.[58] Modalities such Active Release Technique (ART), rolfing, muscle mctivation technique, structural integration, and trigger point therapy are amongst the techniques utilized by these professionals.[58]

D.7.2 *Stretching*

Static stretching and proprioceptive neuromuscular facilitation (PNF) stretching are the two most common ways to stretch short, tight muscles.[58] Static stretching normally involves using stretches that hold the target muscle in a lengthened position. Through autogenic inhibition, this method allows for increases in passive range-of-motion.[58] Static stretches are typically held for at least 30 seconds. PNF stretching comes in a variety of forms but most commonly is performed by stretching the tight muscle, isometrically contracting the muscle, and then stretching the muscle further.[58]

D.7.3 *Joint Mobilization*

The goal of joint mobilization is to help increase extensibility of a joint capsule by breaking up adhesions and/or stretching the capsule itself.[58] This is important to increase range of motion within a joint.[58] A variety of techniques are demonstrated on Kelly Starrett's website (MobilityWod.com) and his book and involve the use of stretch bands to provide distraction at a given joint including the ankle.

D.8 Summary

Overall, the squat maneuver is a very complex exercise, yet it is still the most common lower body strengthening exercise used by Strength and Conditioning Professionals. There are many compensations people make in an attempt to properly execute the squat. Turning the toes outward is a common compensation that increases the risk of placing sheer forces on the knee joint. The Overhead Squat variation keeps the torso in the most upright position, correlating with the need of ankle dorsiflexion range-of-motion to properly execute the movement. Therefore, the purpose of this study is to increase ankle dorsiflexion range-of-motion and observe if that variable leads to better overall positioning during the overhead squat maneuver.

Appendix E

SPSS ANCOVA DATA TABLES

Univariate Analysis of Variance

[DataSet1]

Between-Subjects Factors

		N
Group	1.0	14
	2.0	16
	3.0	14

Descriptive Statistics

Dependent Variable: FinalRDF

Group	Mean	Std. Deviation	N
1.0	44.786	5.8727	14
2.0	48.250	8.0042	16
3.0	49.429	4.9258	14
Total	47.523	6.6279	44

Levene's Test of Equality of Error Variances[a]

Dependent Variable: FinalRDF

F	df1	df2	Sig.
1.594	2	41	.216

Tests of Between-Subjects Effects

Dependent Variable: FinalRDF

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	1007.308*	3	335.833	15.240	.000	.533
Intercept	236.499	1	236.499	10.732	.002	.212
BaseRDF	843.308	1	843.308	38.268	.000	.489
Group	344.628	2	172.314	7.819	.001	.281
Error	881.478	40	22.037			
Total	101259.000	44				
Corrected Total	1888.977	43				

a. R Squared = .533 (Adjusted R Squared = .498)

Estimated Marginal Means

Group

Estimates

Dependent Variable: FinalRDF

Group	Mean	Std. Error	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
1.0	43.335*	1.276	40.755	45.914
2.0	49.857*	1.202	47.427	52.286
3.0	49.044*	1.256	46.505	51.582

a. Covariates appearing in the model are evaluated at the following values: BaseRDF = 39.295.

Pairwise Comparisons

Dependent Variable: FinalRDF

(I) Group	(J) Group	Mean Difference (I-J)	Std. Error	Sig.[b]	95% Confidence Interval for Difference[b] Lower Bound	Upper Bound
1.0	2.0	-6.522*	1.788	.002	-10.989	-2.055
	3.0	-5.709*	1.783	.008	-10.163	-1.254
2.0	1.0	6.522*	1.788	.002	2.055	10.989
	3.0	.813	1.748	1.000	-3.555	5.181
3.0	1.0	5.709*	1.783	.008	1.254	10.163
	2.0	-.813	1.748	1.000	-5.181	3.555

Based on estimated marginal means

*. The mean difference is significant at the

b. Adjustment for multiple comparisons: Bonferroni.

Univariate Tests

Dependent Variable: FinalRDF

	Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Contrast	344.628	2	172.314	7.819	.001	.281
Error	881.478	40	22.037			

The F tests the effect of Group. This test is based on the linearly independent pairwise comparisons among the estimated marginal means.

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  /CRITERIA=ALPHA(.05)
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Univariate Analysis of Variance

[DataSet1]

Between-Subjects Factors

		N
Group	1.0	14
	2.0	16
	3.0	14

Descriptive Statistics

Dependent Variable: FinalLDF

Group	Mean	Std. Deviation	N
1.0	44.786	5.7268	14
2.0	47.000	6.8993	16
3.0	48.857	4.6881	14
Total	46.886	5.9892	44

Levene's Test of Equality of Error Variances[a]

Dependent Variable: FinalLDF

F	df1	df2	Sig.
.368	2	41	.694

Tests the null hypothesis that the error variance of the dependent variable is equal across groups.

a. Design: Intercept + BaseLDF + Group

Tests of Between-Subjects Effects

Dependent Variable: FinalLDF

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	792.818[a]	3	264.273	14.102	.000	.514
Intercept	265.886	1	265.886	14.188	.001	.262
BaseLDF	676.458	1	676.458	36.096	.000	.474
Group	158.121	2	79.060	4.219	.022	.174
Error	749.614	40	18.740			
Total	98269.000	44				
Corrected Total	1542.432	43				

a. R Squared = .514 (Adjusted R S

Estimated Marginal Means

Group

Estimates

Dependent Variable: FinalLDF

Group	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1.0	44.100[a]	1.163	41.750	46.449
2.0	48.063[a]	1.097	45.847	50.280
3.0	48.328[a]	1.160	45.983	50.673

a. Covariates appearing in the model are evaluated at the following values: BaseLDF = 39.205.

Pairwise Comparisons

Dependent Variable: FinalLDF

(I) Group	(J) Group	Mean Difference (I-J)	Std. Error	Sig.[b]	95% Confidence Interval for Difference[b]	
					Lower Bound	Upper Bound
1.0	2.0	-3.964	1.611	.055	-7.989	.061
	3.0	-4.228*	1.636	.041	-8.317	-.139
2.0	1.0	3.964	1.611	.055	-.061	7.989
	3.0	-.264	1.606	1.000	-4.278	3.749
3.0	1.0	4.228*	1.636	.041	.139	8.317
	2.0	.264	1.606	1.000	-3.749	4.278

Based on estimated marginal means

*. The mean difference is significant at the

b. Adjustment for multiple comparisons: Bonferroni.

Univariate Tests

Dependent Variable: FinalLDF

	Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Contrast	158.121	2	79.060	4.219	.022	.174
Error	749.614	40	18.740			

The F tests the effect of Group. This test is based on the linearly independent pairwise comparisons among the estimated marginal means.

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Univariate Analysis of Variance

[DataSet1]

Between-Subjects Factors

		N
Group	1.0	14
	2.0	16
	3.0	14

Descriptive Statistics

Dependent Variable: FinalTorso

Group	Mean	Std. Deviation	N
1.0	104.315308	16.3752358	14
2.0	98.9457451	15.6327218	16
3.0	87.1225080	16.9803100	14
Total	96.8923032	17.4376797	44

Levene's Test of Equality of Error Variances[a]

Dependent Variable: FinalTorso

F	df1	df2	Sig.
.176	2	41	.839

Tests the null hypothesis that the error variance of the dependent variable is equal across groups.

a. Design: Intercept + BaseTorso + Group

Tests of Between-Subjects Effects

Dependent Variable: FinalTorso

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	8831.992[a]	3	2943.997	27.753	.000	.675
Intercept	698.928	1	698.928	6.589	.014	.141
BaseTorso	6656.827	1	6656.827	62.754	.000	.611
Group	668.759	2	334.379	3.152	.054	.136
Error	4243.133	40	106.078			
Total	426152.336	44				
Corrected Total	13075.125	43				

a. R Squared = .675 (Adjusted R Squared = .651)

Estimated Marginal Means

Group

Estimates

Dependent Variable: FinalTorso

Group	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1.0	101.789[a]	2.771	96.188	107.389
2.0	97.102[a]	2.585	91.877	102.328
3.0	91.756[a]	2.814	86.068	97.443

a. Covariates appearing in the model are evaluated at the following values: BaseTorso = 102.136210772

Pairwise Comparisons

Dependent Variable: FinalTorso

(I) Group	(J) Group	Mean Difference (I-J)	Std. Error	Sig.[b]	95% Confidence Interval for Difference[b]	
					Lower Bound	Upper Bound
1.0	2.0	4.686	3.770	.663	-4.735	14.108
	3.0	10.033*	3.996	.049	.047	20.019
2.0	1.0	-4.686	3.770	.663	-14.108	4.735
	3.0	5.347	3.857	.520	-4.291	14.984
3.0	1.0	-10.033*	3.996	.049	-20.019	-.047
	2.0	-5.347	3.857	.520	-14.984	4.291

Based on estimated marginal means

*. The mean difference is significant at the

b. Adjustment for multiple comparisons: Bonferroni.

Univariate Tests

Dependent Variable: FinalTorso

	Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Contrast	668.759	2	334.379	3.152	.054	.136
Error	4243.133	40	106.078			

The F tests the effect of Group. This test is based on the linearly independent pairwise comparisons among the estimated marginal means.

```
UNIANOVA FinalDepth BY Group WITH BaseDepth
  /METHOD=SSTYPE(3)
  /INTERCEPT=INCLUDE
  /EMMEANS=TABLES(Group) WITH(BaseDepth=MEAN) COMPARE ADJ(BONFERRONI)
  /PRINT=ETASQ HOMOGENEITY DESCRIPTIVE
  /CRITERIA=ALPHA(.05)
  /DESIGN=BaseDepth Group.
```

Univariate Analysis of Variance

[DataSet1]

Between-Subjects Factors

		N
Group	1.0	14
	2.0	16
	3.0	14

Descriptive Statistics

Dependent Variable: FinalDepth

Group	Mean	Std. Deviation	N
1.0	88.2981773	10.0554676	14
2.0	84.6529145	14.1489788	16
3.0	81.0215170	14.5497891	14
Total	84.6573262	13.1538899	44

Levene's Test of Equality of Error Variances[a]

Dependent Variable: FinalDepth

F	df1	df2	Sig.
2.736	2	41	.077

Tests the null hypothesis that the error variance of the dependent variable is equal across groups.

a. Design: Intercept + BaseDepth + Group

Tests of Between-Subjects Effects

Dependent Variable: FinalDepth

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	6050.846[a]	3	2016.949	58.074	.000	.813
Intercept	63.739	1	63.739	1.835	.183	.044
BaseDepth	5680.197	1	5680.197	163.550	.000	.803
Group	539.608	2	269.804	7.768	.001	.280
Error	1389.222	40	34.731			
Total	322782.034	44				
Corrected Total	7440.067	43				

a. R Squared = .813 (Adjusted R Squared = .799)

Estimated Marginal Means

Group

Estimates

Dependent Variable: FinalDepth

Group	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1.0	89.507[a]	1.578	86.318	92.696
2.0	83.702[a]	1.475	80.721	86.684
3.0	80.900[a]	1.575	77.717	84.083

a. Covariates appearing in the model are evaluated at the following values: BaseDepth = 91.18

Pairwise Comparisons

Dependent Variable: FinalDepth

(I) Group	(J) Group	Mean Difference (I-J)	Std. Error	Sig.[b]	95% Confidence Interval for Difference[b]	
					Lower Bound	Upper Bound
1.0	2.0	5.804*	2.163	.032	.399	11.210
	3.0	8.607*	2.230	.001	3.035	14.179
2.0	1.0	-5.804*	2.163	.032	-11.210	-.399
	3.0	2.802	2.158	.604	-2.590	8.194
3.0	1.0	-8.607*	2.230	.001	-14.179	-3.035
	2.0	-2.802	2.158	.604	-8.194	2.590

Based on estimated marginal means

*. The mean difference is significant at the

b. Adjustment for multiple comparisons: Bonferroni.

Univariate Tests

Dependent Variable: FinalDepth

	Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Contrast	539.608	2	269.804	7.768	.001	.280
Error	1389.222	40	34.731			

The F tests the effect of Group. This test is based on the linearly independent pairwise comparisons among the estimated marginal means.

```
UNIANOVA FinalShin BY Group WITH BaseShin
  /METHOD=SSTYPE(3)
  /INTERCEPT=INCLUDE
  /EMMEANS=TABLES(Group) WITH(BaseShin=MEAN) COMPARE ADJ(BONFERRONI)
  /PRINT=ETASQ HOMOGENEITY DESCRIPTIVE
  /CRITERIA=ALPHA(.05)
  /DESIGN=BaseShin Group.
```

Univariate Analysis of Variance

[DataSet1]

Between-Subjects Factors

		N
Group	1.0	14
	2.0	16
	3.0	14

Descriptive Statistics

Dependent Variable: FinalShin

Group	Mean	Std. Deviation	N
1.0	69.5778793	6.32203828	14
2.0	68.2956310	7.50692365	16
3.0	69.9462820	8.04292179	14
Total	69.2288262	7.19930906	44

Levene's Test of Equality of Error Variances[a]

Dependent Variable: FinalShin

F	df1	df2	Sig.
3.603	2	41	.036

Tests the null hypothesis that the error variance of the dependent variable is equal across groups.

a. Design: Intercept + BaseShin + Group

Tests of Between-Subjects Effects

Dependent Variable: FinalShin

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	1521.335[a]	3	507.112	28.676	.000	.683
Intercept	66.359	1	66.359	3.753	.060	.086
BaseShin	1498.489	1	1498.489	84.737	.000	.679
Group	25.043	2	12.522	.708	.490	.034
Error	707.357	40	17.684			
Total	213104.429	44				
Corrected Total	2228.692	43				

a. R Squared = .683 (Adjusted R Squared = .659)

Estimated Marginal Means

Group

Estimates

Dependent Variable: FinalShin

Group	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1.0	69.803[a]	1.124	67.531	72.075
2.0	69.713[a]	1.063	67.565	71.860
3.0	68.102[a]	1.142	65.794	70.409

a. Covariates appearing in the model are evaluated at the following values: BaseShin = 68.969561

Pairwise Comparisons

Dependent Variable: FinalShin

(I) Group	(J) Group	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1.0	2.0	.091	1.544	1.000	-3.768	3.950
	3.0	1.702	1.605	.886	-2.310	5.713
2.0	1.0	-.091	1.544	1.000	-3.950	3.768
	3.0	1.611	1.579	.941	-2.335	5.557
3.0	1.0	-1.702	1.605	.886	-5.713	2.310
	2.0	-1.611	1.579	.941	-5.557	2.335

Based on estimated marginal means

a. Adjustment for multiple comparisons: Bonferroni.

Univariate Tests

Dependent Variable: FinalShin

	Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Contrast	25.043	2	12.522	.708	.499	.034
Error	707.357	40	17.684			

The F tests the effect of Group. This test is based on the linearly independent pairwise comparisons among the estimated marginal means.

```
UNIANOVA FinalFlare BY Group WITH BaseFlare
  /METHOD=SSTYPE(3)
  /INTERCEPT=INCLUDE
  /EMMEANS=TABLES(Group) WITH(BaseFlare=MEAN) COMPARE ADJ(BONFERRONI)
  /PRINT=ETASQ HOMOGENEITY DESCRIPTIVE
  /CRITERIA=ALPHA(.05)
  /DESIGN=BaseFlare Group.
```

Univariate Analysis of Variance

[DataSet1]

Between-Subjects Factors

		N
Group	1.0	14
	2.0	16
	3.0	14

Descriptive Statistics

Dependent Variable: FinalFlare

Group	Mean	Std. Deviation	N
1.0	1.49572286	.240216321	14
2.0	1.57419743	.254417162	16
3.0	1.53551028	.209710890	14
Total	1.53691870	.233218969	44

Levene's Test of Equality of Error Variances[a]

Dependent Variable: FinalFlare

F	df1	df2	Sig.
.129	2	41	.879

Tests the null hypothesis that the error variance of the dependent variable is equal across groups.

a. Design: Intercept + BaseFlare + Group

Tests of Between-Subjects Effects

Dependent Variable: FinalFlare

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	1.358[a]	3	.453	18.466	.000	.581
Intercept	.125	1	.125	5.097	.030	.113
BaseFlare	1.312	1	1.312	53.519	.000	.572
Group	.097	2	.048	1.968	.153	.090
Error	.981	40	.025			
Total	106.272	44				
Corrected Total	2.339	43				

a. R Squared = .581 (Adjusted R Squared = .549)

Estimated Marginal Means

Group

Estimates

Dependent Variable: FinalFlare

Group	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1.0	1.468[a]	.042	1.383	1.553
2.0	1.565[a]	.039	1.486	1.644
3.0	1.574[a]	.042	1.488	1.659

a. Covariates appearing in the model are evaluated at the following values: BaseFlare = 1.46483009

Pairwise Comparisons

Dependent Variable: FinalFlare

(I) Group	(J) Group	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a] Lower Bound	Upper Bound
1.0	2.0	-.097	.057	.297	-.240	.046
	3.0	-.106	.060	.256	-.255	.044
2.0	1.0	.097	.057	.297	-.046	.240
	3.0	-.009	.058	1.000	-.153	.135
3.0	1.0	.106	.060	.256	-.044	.255
	2.0	.009	.058	1.000	-.135	.153

Based on estimated marginal means

a. Adjustment for multiple comparisons: Bonferroni.

Univariate Tests

Dependent Variable: FinalFlare

	Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Contrast	.097	2	.048	1.968	.153	.090
Error	.981	40	.025			

The F tests the effect of Group. This test is based on the linearly independent pairwise comparisons among the estimated marginal means.

```
UNIANOVA FinalFootwidth BY Group WITH BaseFootwidth
  /METHOD=SSTYPE(3)
  /INTERCEPT=INCLUDE
  /EMMEANS=TABLES(Group) WITH(BaseFootwidth=MEAN) COMPARE ADJ(BONFERRONI)
  /PRINT=ETASQ HOMOGENEITY DESCRIPTIVE
  /CRITERIA=ALPHA(.05)
  /DESIGN=BaseFootwidth Group.
```

Univariate Analysis of Variance

[DataSet1]

Between-Subjects Factors

		N
Group	1.0	14
	2.0	16
	3.0	14

Descriptive Statistics

Dependent Variable: FinalFootwidth

Group	Mean	Std. Deviation	N
1.0	536.107220	94.6120822	14
2.0	542.256849	91.3647275	16
3.0	516.021471	73.4108072	14
Total	531.952529	85.8857157	44

Levene's Test of Equality of Error Variances[a]

Dependent Variable: FinalFootwidth

F	df1	df2	Sig.
.309	2	41	.736

Tests the null hypothesis that the error variance of the dependent variable is equal across groups.

a. Design: Intercept + BaseFootwidth + Group

Tests of Between-Subjects Effects

Dependent Variable: FinalFootwidth

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	178289.40[a]	3	59429.800	17.115	.000	.562
Intercept	5125.252	1	5125.252	1.476	.232	.036
BaseFootwidth	172795.696	1	172795.696	49.763	.000	.554
Group	5067.312	2	2533.656	.730	.488	.035
Error	138893.915	40	3472.348			
Total	12768017.0	44				
Corrected Total	317183.315	43				

a. R Squared = .562 (Adjusted R Squared = .529)

Estimated Marginal Means

Group

Estimates

Dependent Variable: FinalFootwidth

Group	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1.0	540.220[a]	15.760	508.369	572.072
2.0	538.432[a]	14.742	508.638	568.225
3.0	516.280[a]	15.749	484.451	548.110

a. Covariates appearing in the model are evaluated at the following values: BaseFootwidth = 523.0725

Pairwise Comparisons

Dependent Variable: FinalFootwidth

(I) Group	(J) Group	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1.0	2.0	1.789	21.594	1.000	-52.172	55.750
	3.0	23.940	22.279	.867	-31.732	79.612
2.0	1.0	-1.789	21.594	1.000	-55.750	52.172
	3.0	22.151	21.573	.932	-31.756	76.058
3.0	1.0	-23.940	22.279	.867	-79.612	31.732
	2.0	-22.151	21.573	.932	-76.058	31.756

Based on estimated marginal means

a. Adjustment for multiple comparisons: Bonferroni.

Univariate Tests

Dependent Variable: FinalFootwidth

	Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Contrast	5067.312	2	2533.656	.730	.488	.035
Error	138893.915	40	3472.348			

The F tests the effect of Group. This test is based on the linearly independent pairwise comparisons among the estimated marginal means.

```
UNIANOVA FinalEversion BY Group WITH BaseEversion
  /METHOD=SSTYPE(3)
  /INTERCEPT=INCLUDE
  /EMMEANS=TABLES(Group) WITH(BaseEversion=MEAN) COMPARE ADJ(BONFERRONI)
  /PRINT=ETASQ HOMOGENEITY DESCRIPTIVE
  /CRITERIA=ALPHA(.05)
  /DESIGN=BaseEversion Group.
```

Univariate Analysis of Variance

[DataSet1]

Between-Subjects Factors

		N
Group	1.0	14
	2.0	16
	3.0	14

Descriptive Statistics

Dependent Variable: FinalEversion

Group	Mean	Std. Deviation	N
1.0	1.14805273	.097722752	14
2.0	1.07904434	.088086794	16
3.0	1.11103510	.080080433	14
Total	1.11118043	.091430630	44

Levene's Test of Equality of Error Variances[a]

Dependent Variable: FinalEversion

F	df1	df2	Sig.
.006	2	41	.994

Tests the null hypothesis that the error variance of the dependent variable is equal across groups.

a. Design: Intercept + BaseEversion + Group

Tests of Between-Subjects Effects

Dependent Variable: FinalEversion

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	.092[a]	3	.031	4.562	.008	.255
Intercept	.040	1	.040	5.947	.019	.129
BaseEversion	.056	1	.056	8.376	.006	.173
Group	.014	2	.007	1.057	.357	.050
Error	.268	40	.007			
Total	54.687	44				
Corrected Total	.359	43				

a. R Squared = .255 (Adjusted R Squared = .199)

Estimated Marginal Means

Group

Estimates

Dependent Variable: FinalEversion

Group	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1.0	1.121[a]	.024	1.074	1.169
2.0	1.088[a]	.021	1.046	1.129
3.0	1.128[a]	.023	1.082	1.174

a. Covariates appearing in the model are evaluated at the following values: BaseEversion = 1.073675

Pairwise Comparisons

Dependent Variable: FinalEversion

(I) Group	(J) Group	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1.0	2.0	.034	.032	.902	-.047	.115
	3.0	-.006	.034	1.000	-.092	.079
2.0	1.0	-.034	.032	.902	-.115	.047
	3.0	-.040	.030	.564	-.115	.035
3.0	1.0	.006	.034	1.000	-.079	.092
	2.0	.040	.030	.564	-.035	.115

Based on estimated marginal means

a. Adjustment for multiple comparisons: Bonferroni.

Univariate Tests

Dependent Variable: FinalEversion

	Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Contrast	.014	2	.007	1.057	.357	.050
Error	.268	40	.007			

The F tests the effect of Group. This test is based on the linearly independent pairwise comparisons among the estimated marginal means.