

CAN AN INTEGRATED CORRECTIVE EXERCISE INTERVENTION MITIGATE RANGE
OF MOTION CHANGES POST HIGH INTENSITY EXERCISE IN FEMALE ATHLETES?

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ABSTRACT

Johanna Leigh White: Can an Integrated Corrective Exercise Intervention Mitigate Range of Motion Changes Post High Intensity Exercise in Female Athletes?
(Under the direction of Darin Padua)

Decreased range of motion has become a risk factor associated with ACL injuries. There is a need for an intervention to improve range of motion post fatigue. The purpose of this study is to determine if a corrective exercise intervention helps mitigate lower extremity range of motion post an acute high intensity exercise exposure, and determine if there is a change in range of motion post an acute high intensity exercise exposure. 20 healthy, physically active females between 18-24 years old were randomized to control or treatment groups. Session I subjects had measurements taken, exposed to high intensity exercise and measurements taken post. At 24 hours subjects had measurements taken before and after intervention. Time pre-intervention to post-intervention hamstring showed a significant change ($p = .047$) in the intervention group. From baseline to post fatigue, 24 hours post fatigue there was a significant decrease in hamstring motion ($p = .021$).

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CHAPTER I - INTRODUCTION

Physical activity participation is one of the strongest risk factors for musculoskeletal injury (Conn, Annest, & Gilchrist, 2003). According to the National Collegiate Athletic Association (NCAA) an average of 28.1 injuries per 1000 athlete exposures annually (Hootman, J. M., Dick, R., & Agel, 2007). Lower extremity injury represents a majority of injuries sustained during athletic participation (Fernandez, Yard, & Comstock, 2007). Recent evidence suggests severe lower extremity injury rates are increasing. For example, one study found from 1988-2004 there was a 1.3% increase in anterior cruciate ligament (ACL) injuries (Hootman, J. M., Dick, R., & Agel, 2007). Severe musculoskeletal injury, such as ACL rupture can be debilitating, requiring surgery for full repair and return to play. This can be timely and costly to both the patient and society (Cumps, Verhagen, Annemans, & Meeusen, 2008). ACL surgeries typically require 6-9 months of rehabilitation before being allowed for full return to play to sport. It was reported that surgical interventions for ACL reconstruction had an average societal cost of \$38,121. Choosing to forego surgery and complete long-term rehabilitation was reported to have an average societal cost of \$88,538 per injury (Mather et al., 2013). Thus, it is important to find preventative strategies in order to minimize risk and occurrence of ACL injuries in sport and reduce societal costs.

There are many risk factors associated with lower extremity injuries, specifically ACL rupture. Decreased range of motion has recently become a known modifiable risk factor associated with ACL injuries. Total hip transverse plane arc of motion has consistently been identified as a risk factor associated with secondary knee joint injury. One study found a link

between decreased hip internal rotation (26.4 degrees) with those who have previously suffered a non-contact ACL injury compared to those who do not (39.0 degrees) (Gomes, de Castro, & Becker, 2008). Hip extension range of motion helps aid landing and a reduced hip extension range of motion has been shown to be a risk factor for non-contact ACL injury (Shultz et al., 2015). Decreased knee flexion range of motion has been indicated as an important injury risk factor for ACL injury (Shultz et al., 2015). Along with that, decreased dorsiflexion range of motion has been shown to reduce knee flexion range of motion and thus lead to an increased risk for non-contact ACL injury (Dill, Begalle, Frank, Zinder, & Padua, 2014; Fong et al., 2011). It is also important to consider whether fatigue impacts range of motion. Previous studies have observed a decrease in neuromuscular control leading to increased hip internal rotations when landing on a single leg with an induced fatigue protocol (Borotikar, Newcomer, Koppes, & McLean, 2008). Although we know modifiable risk factors associated with ACL ruptures, there is a need for further research on how to prevent this in the long term.

Currently there is a gap in the evidence investigating the long term effects of interventions aimed at improving range of motion deficits and whether these corrective exercise interventions can mitigate deleterious decreases in range of motion after fatigue exposure. There is a lack of research on how an intervention could help improve hip arc, hip extension, knee flexion, and ankle dorsiflexion range of motions and whether this intervention is effective long term. There is also a lack of research on whether interventions help improve range of motion during an acute bout of fatigue and how this can help prevent ACL injuries. There are many factors associated with ACL injuries but there is little being done to prevent ACL injuries in the athletic population.

It is essential to focus on hip, knee, and ankle range of motion and how it is linked to increased risk of non-contact ACL injuries. There needs to be evidence as to whether a corrective exercise intervention can help mitigate these range of motion deficits, improving risk for lower extremity injury. There also needs to be further research as to whether this intervention can help improve range of motion even through an acute bout of fatigue. The purpose of this study is to 1) determine if an intervention helps mitigate hip arc, hip extension, hamstring, great toe, and ankle dorsiflexion range of motion post fatigue inducing exercise 2) determine if there is a change in range of motion for hip arc, hip extension, hamstring, great toe, and ankle dorsiflexion post fatigue inducing exercise.

Research Questions

Research Question 1: Does a corrective exercise intervention delivered 24 hours following an acute high intensity exercise exposure minimize range of motion deficits in active females?

Research Question 2: Are there differences in range of motion changes immediately following and 24 hours post an acute high intensity exercise exposure in active females?

Research Hypotheses

1) A corrective exercise intervention delivered 24 hours post an acute high intensity exercise exposure will mitigate range of motion changes in active females.

Dependent variables: hip arc, hip extension, hip abduction, hamstring extension, ankle dorsiflexion, great toe extension

Independent variables: Time at 2 levels (pre corrective exercise intervention, post corrective exercise intervention)

2) There will be increases in range of motion immediately following acute high intensity exercise exposure and there will be a decrease in range of motion 24 hours post acute high intensity exercise exposure.

Dependent variables: hip arc, hip extension, hip abduction, hamstring extension, ankle dorsiflexion, great toe extension

Independent variables: Time at 3 levels (pre acute high intensity exercise exposure, post acute high intensity exercise exposure, 24 hours post acute high intensity exercise exposure)

Clinical Significance

If there is an improvement in range of motion then this intervention could be used as a means to help prevent ACL injury in athletes, specifically non-contact female injuries. This intervention could be implemented with teams after high intensity exercise (games or practices) to prevent injury, which would decrease time loss from sport/work, cost to individual and society, and physical and emotional distress over injury. Fatigue has been linked to increased risk of injury, therefore if we can determine that this intervention helps improve range of motion during fatigue then we can help prevent debilitating MSK injury during fatiguing exercise.

CHAPTER II – LITERATURE REVIEW

Epidemiology of Lower Extremity Musculoskeletal Injury in Sport

Participation in sport is a primary risk factor for musculoskeletal injuries (Caine, Maffulli, & Caine, 2008). These injuries can range in severity and time lost, with more severe injuries having a larger negative impact. Anterior cruciate ligament (ACL) injury or sprain has been classified as a severe injury due to impact of time lost, cost to individual and society, and long-term consequences (Mather et al., 2013; Murrell, Maddali, Horovitz, Oakley, & Warren, 2001; Myklebust, 2005). Sixteen years of injury surveillance data collected using the National Collegiate Athletic Association (NCAA) observed an injury incidence of 28.1 injuries per 1000 athlete exposures in male and female collegiate athletes. Lower extremity injury accounted for over 50% of all injuries, with the majority being ankle ligament injuries and noted an average 1.3% increase in anterior cruciate ligament injuries annually (Hootman, J. M., Dick, R., & Agel, 2007). In the United States 7 million Americans receive medical attention for sport and recreation activities annually, with the highest percentage (39%) being lower extremity injuries (Conn et al., 2003). One study showed in female collegiate lacrosse players more than 60% of game and practice injuries were lower extremity injuries, specifically musculoskeletal knee sprains and strains from non-contact activity (Hootman, J. M., Dick, R., & Agel, 2007). Based on the severity and frequency of ACL injury in sport, there is need for a better understanding of how to prevent future injuries.

Anterior cruciate ligament tears occur at a much great rate than other knee ligament and

musculoskeletal injuries. In a prospective study it was found that 27% of all injuries in emergency departments were sport activities and of those injuries ACL tears were seven times more likely than any other injury (Nielsen & Yde, 1991). Evidence has shown non contact occurs more frequently compared to direct or indirect contact for ACL injuries by 75% (Boden, Sheehan, Torg, & Hewett, 2010). Non-contact ACL injury is defined as, “absence of a direct blow to the lower extremity” (T. E. Hewett, 2005). The movement injury risk prediction for non contact is associated with: increased pelvic tilt, hip adduction, dynamic valgus with medial knee displacement, shear force at the knee, tibial internal rotation, and axial load from the ground (Timothy E Hewett, Ford, Hoogenboom, & Myer, 2010). Considering non-contact ACL injuries are more common than contact injuries it is important for research to focus on prevention of non contact ACL injuries.

It is shown that active females are at a two to eightfold greater risk of non-contact ACL injuries than active males (Boden et al., 2010). One study looking at incidence rates for ACL injuries across high schools and colleges found females (incidence rate = .112 out of 1000 person-days) to be twice as likely to receive an ACL injury compared to their male counterparts (incidence rate = .063 per 1000 person-days) (Beynnon et al., 2014). Not only are females in general at a greater risk but college-aged females are shown to be more at risk for non-contact ACL injury. One study reported 48 ACL injuries out of 320,719 athlete exposures at colleges (incidence rate = .150) and 53 injuries with 873,057 athlete exposures at high schools (incidence rate = .061) (Beynnon et al., 2014). There are multiple factors contributing to the increased risk of ACL injury for active females, including increased knee valgus moment, ligament size, joint laxity, and hormonal effects of estrogen on the ACL (Boden et al., 2010). It is important for research to focus on college aged active females for prevention of ACL injuries based on the

significant increased risk in this population.

Burden of Severe ACL Injury

Long-term Consequences of ACL Injury

Anterior cruciate ligament injuries result in long term consequences effecting return to play and joint health. There is more than 50% incidence rate of early onset osteoarthritis in patients who have experienced an ACL injury (Lohmander, Englund, Dahl, & Roos, 2007). Osteoarthritis is defined as, “focal areas of loss of cartilage in synovial joints associated with varying degrees of osteophyte formation, subchondral bone change, and synovitis (Lohmander et al., 2007). Most patients who experience ACL injuries are younger than 30, leading to early onset of osteoarthritis, decreasing the quality of joint and life in ages between 30-50 years of age (Lohmander et al., 2007). When returning to play after an ACL injury there is a decrease in quality of play compared to pre-injury, whether this is from the injury or from discontinuation of sport for multiple months. The rate of re-injury is as high as 13% for patients who have had reconstructive surgery (Myklebust, 2005). Based on the decreased quality of play and increased risk of osteoarthritis in patients who experience ACL injuries, it is important for research to conclude preventive measures for at risk populations.

Socioeconomic Costs

Not only are ACL tears detrimental to the involved patient but also they are costly to society. ACL tears require expensive surgical interventions and long-term rehabilitation. There is also an associated time loss when undergoing an intensive surgery and rehabilitation protocol. These factors cost the patient and health care system. It is shown that using the surgical intervention route is cheaper than just completing a rehabilitation program for ACL reconstruction, costing society \$38,121 for the surgical intervention and a long-term

rehabilitation intervention costing \$88,538 (Mather et al., 2013). When compared to other knee injuries, ACL reconstruction was more costly and required more visits, which leads to more time loss. Those who underwent ACL reconstruction had an average of 27 treatment visits and cost an average of \$11,157 for the individual (Gianotti, Marshall, Hume, & Bunt, 2009).

Biomechanics as a Risk Factor For ACL Injury

There is an association of biomechanics being an intrinsic injury risk factor, specifically for the lower extremity (Murphy, Connolly, & Beynnon, 2003). One study measured preseason flexibility for hamstrings, quadriceps, gastrocnemius and hip adductors in male professional soccer players. For hamstring and quadriceps there was a significant difference ($P = 0.02$ and $P = 0.047$ respectively) in muscle flexibility between those injured and uninjured during the season (Witvrouw, Danneels, Asselman, D'Have, & Cambier, 2003). Lower knee peak flexion angle along with greater vertical ground reaction force and quadriceps activation has been shown to increase risk of injury, especially for non contact anterior cruciate ligament sprain by increasing the anterior tibial shear force (Leppänen et al., 2016). Although biomechanics have been found to induce ACL injury, it is not the only factor associated with increased risk of lower extremity injury.

Decreased Range of Motion Leads to Increased Injury Risk

Biomechanics are an important factor to consider when attempting to prevent ACL injury, but there are other factors to also consider. Range of motion has recently been linked to an increased risk of ACL injury, specifically hip arc, hip extension, knee flexion, and ankle dorsiflexion. This section will delve into how range of motion is key in prevention of non-contact ACL injuries in active females.

Total Hip Arc of Motion and Injury Risk For Non-contact ACL Injury in the Active Female

Hip arc is the combination of hip internal and external rotation, usually measured in a prone position with knees flexed to 90 degrees. Normal hip arc range of motion is defined as being between 70-80 degrees (Gomes et al., 2008). The term hip arc of motion has been used more recently when referencing hip range of motion because it has been seen that people may lack internal or external rotation of the hip but make up for it in the other, leading to an overall normal range of 80 degrees hip arc of motion. One study found significant results ($P < .05$) that peak valgus moment occurred with hip internal rotation and hip flexion, most specifically in females. There was further discussion in that hip neuromuscular control and isolated hip range of motion measures should be further investigated to in ACL research (McLean, Huang, & Van Den Bogert, 2005). One study looking at soccer players found a decrease in external, internal and arc in subjects who experienced ACL ruptures compared to those who did not ($p < .001$, $p < .484$, $p < .001$ respectively) (Gomes et al., 2008). There have been associations between hip arc of motion and increased risk of ACL tears but the research is shallow and limited. It is necessary for further investigations that look specifically at hip arc range of motions to determine further implications and produce preventative strategies.

Hip Extension and Injury Risk For Non-contact ACL Injury in the Active Female

Hip extension range of motion is an important risk factor in controlling hip motion during landing in females (Shultz et al., 2015). In subjects with poor movement qualities it has been shown that there is a decrease in hip extension after induced fatigue (Frank, 2016). It is necessary to implement an intervention that improves long-term hip extension range of motion to prevent non-contact female ACL injuries.

Knee Flexion and Injury Risk For Non-contact ACL Injury in the Active Female

Peak knee flexion moment has become one of the prime risk factors for non-contact ACL injuries in females (Shultz et al., 2015). One study looking at females who experienced ACL ruptures had smaller knee flexion range of motion than those who did not become injured (Leppänen et al., 2016). An intervention improving knee flexion range of motion may help with biomechanical risk factors associated with ACL injury (Favre, Clancy, Dowling, & Andriacchi, 2016). It is necessary to find an intervention that improves long-term knee flexion range of motion in order aid in the prevention of non-contact ACL injury in females.

Ankle Dorsiflexion and Injury Risk For Non-contact ACL Injury in the Active Female

There is evidence showing an increased injury risk factor for ACL rupture in individuals who display a larger knee valgus moment, decreased knee flexion, and larger ground reaction forces (Fong et al., 2011; Frank, 2016). Evidence shows that there is less knee flexion moment and greater ground reaction forces with smaller amounts of ankle dorsiflexion displacement. This evidence also demonstrates how there is an association between decreased dorsiflexion range of motion and greater knee valgus moment during landing tasks (Dill et al., 2014; Fong et al., 2011). Improvement in dorsiflexion range of motion is an important risk factor that needs to be addressed in the prevention of ACL rupture and improvement in knee valgus and flexion moments.

Interventions to Improve Range of Motion

Based on the aforementioned literature there is an association between decreased hip motion arc, knee flexion, hip flexion, and ankle dorsiflexion and an increased risk of lower extremity musculoskeletal injury. Research should focus on improving hip, knee, and ankle range of motion in order to help prevent ACL injury in active, college-aged females.

Static Stretching

Research has evaluated static and dynamic stretching as ways to improve range of motion and ultimately improve performance. There has been evidence found to support stretching being implemented before physical activity beneficial but the effects were considered short term (Woods, Bishop, & Jones, 2007). Based on research and common knowledge of autogenic inhibition: when a muscle is put on stretch the Golgi Tendon Organs are activated and cause a sudden contraction of the agonist, then a contraction of the antagonist and relaxation of the agonist, allowing the muscle to lengthen; stretching can be useful in increasing range of motion. It is important to find an intervention to increase hip range of motion that has a lasting, long-term effect. It has been shown that static stretching regularly over a six-week time span improved plasticity of the muscle and increased range of motion ($P = .001$) (Yuktasir & Kaya, 2009). Thus, stretching is an effective tool to help improve initial range of motion but it may not be the most effective approach for long-term improvements. An integrated study needs to look at more efficient and effective procedures for improving range of motion.

Foam Rolling

There has been an increase in the literature discussing foam rolling as a means for improving range of motion and decreasing myofascial adhesions. A systematic review looked at the effects of foam rolling on hip, knee and ankle range of motion. The results showed a significant increase in hip, knee, and ankle range of motion ($P < .05$, $P < .001$, $P < .05$) respectively (Cheatham, Kolber, Cain, & Lee, 2015). Another study found foam rolling to be an effective tool to reduce delayed onset of muscle soreness and improve range of motion (Pearcey et al., 2015). Foam rolling is an option for improving range of motion, but there is not enough evidence present to determine if it is effective or efficient enough to prevent non-contact ACL

injury. Further research is needed to determine if foam rolling is enough or if there should be another approach integrated.

Deep Muscle Percussive Stimulation

It is also important to address myofascial deficits in subjects who have increased risk movement patterns for ACL injuries in order to improve range of motion. One study looked at the effects of foam rolling on myofascial release improving knee range of motion. They found significant ($P < 0.001$) results in that people who foam rolled their lower extremity gained 10 degrees of motion (MacDonald et al., 2013). Range of motion can be improved through the use of muscle inhibition and relaxation (Atha & Wheatley, 1976). The RAPTOR by Hyperice will be implemented in order to apply deep percussive stimulation to the lower extremity with each intervention in order to help release myofascial adhesions within the tissues and inhibit overactive muscles. The amount of time decreased significantly in treatment time using The RAPTOR because you only do 30 seconds to 1 minute of treatment compared to 8-10 minutes for foam rolling. It also requires less work from the clinician in that they do not have to use their thumb or put their bodies in uncomfortable positions in order to complete myofascial release treatments. There has been little to no research done on devices such as The RAPTOR so it is necessary to include this in this intervention in order to determine if there is a possibility that deep percussive stimulation along with an intervention provides significant results. This would promote further research to be done specifically for The RAPTOR so that clinicians can grasp a better understanding and knowledge base of practicing deep muscle percussive stimulation into their practice.

Intervention on Improving Range of Motion

The aforementioned evidence shows there is an increase in range of motion with different methods of intervention. Static stretching can improve range of motion through autogenic inhibition (Yuktasir & Kaya, 2009). Foam rolling can improve range of motion through inhibition of overactive muscles (Cheatham et al., 2015). Deep muscle percussive stimulation can inhibit overactive muscles (Atha & Wheatley, 1976). One systematic review reported that massage was the most effective tool in reducing markers of muscle stress, as well as compression and water immersion (Dupuy, Douzi, Theurot, BOSQUET, & DUGUE, 2018). There is lack of evidence on what the most effective approach is to improvements in range of motion post fatigue. Known interventions should be combined to determine if inhibiting overactive muscles, stretching overactive muscles, and activating underactive muscles can be used as a form of corrective exercise intervention to be implemented post high intensity exercise exposure to mitigate range of motion changes.

Fatigue and its Effect on Range of Motion

Research has shown that fatigue alters biomechanics and range of motion in high-risk movement groups. There has been no research to focus on how fatigue affects hip arc range of motion in high-risk movers. One study looked at multiple ranges of motions for the lower extremity after a bout of fatigue induced strength training. It found significant ($P < .005$) results in increased hip flexion but did not find significant results in hip extension (Sparto, Parnianpour, Reinsel, & Simon, 1997). It has been shown that fatigue-inducing exercise can reduce ankle range of motion in active females (Christina, White, & Gilchrist, 2001). Fatiguing exercise has shown to reduce control of knee motion during landing (Orishimo & Kremenec, 2006), which can give evidence to potential changes in range of motion of the knee joint during functional

testing. Further research should investigate specific changes in range of motion from baseline to post high intensity exercise exposure to better understand the effects of fatigue on range of motion in the lower extremity.

CHAPTER III – MATERIALS AND METHODS

Research Design

This study was conducted as a randomized blind control trial with one control group and one treatment group. The first aim of this study was to determine if an acute integrated recovery intervention program could mitigate the effects of high intensity exercise exposure on range of motion. The second aim of this study was to determine if there was a change in range of motion from pre exercise exposure to immediately post exercise exposure and twenty-four hours post exercise exposure. The design of this study allowed us to determine whether the intervention did in fact improve range of motion based on measures taken between both the control and treatment groups.

Participants

This study consisted of 20 female subjects, 10 control subjects and 10 treatment subjects. Participants in this study were kept between 18-24 years of age. These subjects were healthy college individuals who had a history of competing in field or court sport activities and were physically active at least three times a week for thirty minutes or more. These subjects had no history of lower extremity joint surgery. These subjects had no history of lower extremity injuries in the last six months. All subjects read and signed an informed consent form approved by the Institutional Review Board of the University of North Carolina at Chapel Hill.

Instrumentation

Range of Motion

Lower extremity passive range of motion was measured with a digital inclinometer for active knee extension, hip internal rotation, and hip external rotation (Sanders Group, Inc., Chaska, MN, USA). The inclinometer was used for these ranges of motion due to reliability being more difficult (Roach, San Juan, Suprak, & Lyda, 2013). A standard 8-inch plastic goniometer was used to measure hip extension, hip abduction, great toe extension, straight leg ankle dorsiflexion, and bent leg ankle dorsiflexion. A goniometer was used for these ranges of motion due to reliability being easier (Roach et al., 2013).

Integrated Recovery Intervention Program

The RAPTOR by Hyperice was used as a deep percussive muscle inhibitor to the lower extremity (RAPTOR, Hyperice[®], USA). The areas treated by the RAPTOR were medial and lateral head of gastrocnemius, lateral hamstring, hip adductors, and iliotibial band (ITB).

Procedures

All participants were randomized to either the control or treatment group. Each participant reported to the Sports Medicine Research Lab for their first session where they signed aforementioned IRB consent forms. Each participant wore her own athletic shorts and shirt. Each participant reported on the first day to complete range of motion measurements. They then completed the high intensity exercise program and had post exercise measures taken: range of motion and perceived soreness. This completed session I. After 24 hours each participant reported back for session II where they received range of motion measurements, the corrective exercise intervention or control intervention, and range of motion were taken again. Perceived recovery and soreness were taken before and after intervention and control treatments.

Range of Motion Measurements

Range of motion was taken for the dominant limb of each subject. Five values were recorded for each range of motion.

Hip Internal Rotation

Participants were asked to lay prone (face-down) on a treatment table with their hips in a neutral position and knee flexed to 90 degrees. An investigator internally rotated the participant's hip to the point of first limitation. An inclinometer was placed on the lateral surface of the participant's shank parallel to the fibula bone. The angle relative to the vertical was recorded.

Hip External Rotation

Participants were asked to lay prone (face-down) on a treatment table with their hips in a neutral position and knee flexed to 90 degrees. An investigator externally rotated the participant's hip to the point of first limitation. An inclinometer was placed on the lateral surface of the participant's shank parallel to the fibula bone. The angle relative to the vertical was recorded.

Hip Abduction

The participant was placed in a supine position with her legs in full extension, flat on the table. One researcher stabilized the pelvis by placing a hand on the contralateral anterior superior iliac spine (ASIS) of the leg being tested then grasped the medial aspect of the shank on the leg being measured and passively abducted the leg until the point of first resistance or the participant expressed discomfort. Once this point was reached, a second researcher measured the angle with a standard goniometer with the stationary arm positioned so the distal portion was placed over the contralateral ASIS, the fulcrum over the ipsilateral ASIS, and the movement arm over the long axis of the femur, with the middle of the patella as the distal reference.

Hip Extension

The participant was positioned in a supine position with hip joint positioned over the edge of the table. The participant brought both knees to chest and held this position while the low back, sacrum, and pelvis remained horizontal and were stabilized by the investigator; the participant then relaxed dominant limb which allowed the knee to flex and the thigh to drop down towards the table into the investigator's hand until the point of first resistance was felt by the investigator with the anterior-superior iliac spine being felt to rotate anteriorly. Once the investigator identified this point, a second researcher measured the angle with a goniometer along the lateral aspect of the thigh at the midpoint along a line between the test limb greater trochanter and lateral femoral epicondyle.

Ankle Dorsiflexion Straight Leg

The participant was placed in a supine position with both legs fully extended, the contralateral leg flat on the table and the leg tested propped on a bolster placed at the mid-shaft of the tibia. The investigator stabilized the shank by grasping the tibia/fibula at mid-shaft and grasped the foot with the opposite hand and passively moved the foot into dorsiflexion until the point of first resistance or the participant expressed discomfort. Once this point was reached the investigator measured the angle with a standard goniometer with the stationary arm aligned with the long axis of the fibula and the fulcrum and the movement arm aligned with the long axis of the fifth metatarsal.

Ankle Dorsiflexion Bent Leg

The participant was placed in a supine position with both legs propped on a box, leg tested propped on a bolster placed at the mid-shaft of the tibia. The investigator stabilized the shank by grasping the tibia/fibula at mid-shaft and grasped the foot with the opposite hand and

passively moved the foot into dorsiflexion until the point of first resistance or the participant expressed discomfort. Once this point was reached the investigator measured the angle with a standard goniometer with the stationary arm aligned with the long axis of the fibula and the fulcrum and the movement arm aligned with the long axis of the fifth metatarsal.

Great Toe Extension

The participant was placed in a supine position with both legs fully extended, the contralateral leg flat on the table and the leg tested propped on a bolster placed at the mid-shaft of the tibia. The investigator stabilized the foot and passively moved it into dorsiflexion until the foot was in a neutral position (~0 degrees of dorsiflexion). Once this point was reached the investigator passively extended the great toe until the point of first resistance or the participant expressed discomfort. At this point the investigator measured the angle with a standard goniometer, with the stationary arm aligned parallel to the first ray, the fulcrum centered over the 1st metatarsal-phalangeal joint, and the movement arm placed parallel to the long axis of the 1st metatarsal.

Fatigue Protocol

Each subject was taken to The Exercise Oncology Research Laboratory where they completed the $VO_{2\text{sub-max}}$ and VeT assessment. The Exercise Oncology Research Laboratory was located 25 feet from The Sports Medicine Research Laboratory. Upon arrival to The Exercise Oncology Research Laboratory each subject sat resting in a chair for 5 minutes at which point a member of the research team placed a heart rate monitor around their chest and explained the assessment protocol. Their resting vitals were assessed and a research team member confirmed they did not have restrictions from high-intensity exercise. After vitals and unrestricted exercise participation were determined, each subject was fitted with a breathing mask to measure

breathing gasses during the assessment. They each had 3-5 minutes to get used to breathing through the mask, then performed a 5 minute warm-up on the treadmill at 4.0 mph. After the warm-up the test began using 1-minute stages that began at a speed of 5.0 mph. Each stage increased by 1.0 mph until a speed of 8.0 mph (3rd minute – Stage #4). After the treadmill speed increased to 8.0 mph, each successive 1-minute stage increased speed by 0.5 mph. The test was complete when they reached termination criteria including voluntarily stopping by informing the researchers. Each subject completed the high-intensity exercise protocol exactly 10 minutes after completing the above fitness assessment. The protocol started with each subject running at a speed that was coincident with ~75% of their maximal aerobic capacity. This exercise intensity represented an exercise intensity that was difficult but not near maximal intensity and was a speed that could be maintained for a short distance run (~1 mile), but could not be sustained for longer duration activity. They each ran on the treadmill for 5 minutes, then stepped off the treadmill and performed ten back-to-back jump-landings and 10 split squats (5 on each leg). They each then completed a total of 5 sets of the 5 minute running and 10 jump-landing and 10 split squat intervals. After the final jump landing and split squat interval they rested for 3 minutes and then completed 10 more jump landings, 20 split squats (10 each leg) two times. By the end of the high-intensity exercise exposure, each subject performed 70 total jump-landings and 90 split squats (45 each leg) which took approximately 20 minutes to complete; 45 minutes all together with the running.

Corrective Exercise Intervention

Each participant completed one session of the corrective exercise intervention program twenty four hours post acute high intensity exercise exposure. The intervention consisted of inhibition of overactive muscles, static stretching of overactive muscles, isolated activation of

underactive muscles, and an integrated functional exercise. Overactive muscle inhibition was accomplished using the RAPTOR, focusing on the calf, ITB, hip adductor complex, and lateral hamstring for two minutes at each muscle site bilaterally. Each participant then completed static stretching focusing on the calf, ITB, hip adductor complex, and lateral hamstring for 2X30 seconds. For the static calf stretch they faced a wall in a staggered leg position, leaned against the wall and pushed their lower leg back until a noted stretch was felt in the calf. For the ITB each participant positioned themselves parallel to the wall, pushed their involved hip towards the wall while they stabilized their uninvolved leg in front. For the hip adductors each participant was positioned standing with the uninvolved limb stabilizing in a flexed position while the involved limb reached out to the side away from the body. For the lateral hamstrings each participant was supine on the floor with the uninvolved limb straight out and involved leg hip flexed and adducted keeping the leg straight. Each participant then completed isolated activation of underactive muscles: heel raise 2X10, sidelying hip abduction 2X10, double leg hip bridge 2X10. Finally, each participant then completed functional exercise to incorporate all previously completed components: side step down 2X10, double leg to single leg stabilization 2X10.

Session I

Each participant reported to the Sports Medicine Research Lab for session I where they received pre exercise assessments that included specific gravity, resting heart rate, blood pressure, height, and weight. They then had range of motion measures taken as described above. Once the pre assessments were completed each participant completed the high intensity exercise exposure as previously described. Upon completion of the high intensity exercise exposure range of motion was taken again along with perceived soreness and recovery scales. Each participant

was then sent home for 24 hours where they were instructed to not exercise until the end of testing.

Session II

Each participant then reported back twenty four hours post session I to complete session II. After arrival for session II each participant completed perceived soreness forms and had range of motion measures taken. They then completed their respective treatment sessions. Those in the control group had an electrical stimulation unit applied but not turned on and then had range of motion measures taken post and perceived soreness forms. Those in the corrective exercise intervention group completed the full corrective exercise intervention and then had range of motion measurements taken and perceived soreness forms. All subjects were then done with their respective sessions and were free to leave.

Statistical Analysis

Research Question 1: Each range of motion was taken five times at each time point. An average was taken of all five trials to determine an average for each time point. Change scores were calculated between post-24 hours and post-intervention range of motion values between a control group and corrective exercise intervention group. Independent samples t-tests were carried out to evaluate the effects of the intervention on changes in range of motion between post-24 hours and post-intervention time points. Statistical significance was set at $\alpha < 0.05$. All data were analyzed using SPSS 24.0 statistical software (SPSS, Inc., Chicago, IL).

Research Question 2: Each range of motion was taken five times at each time point. An average was taken of all five trials to determine an average for each time point. A three by two repeated measures ANOVA was used to determine the differences in range of motion between a control group and a corrective exercise intervention group over three time points: pre-fatigue,

immediately post-fatigue, 24 hours post-fatigue. Statistical significance was set at $\alpha < 0.05$. A Tukey post hoc analysis was used for significant results. All data were analyzed using SPSS 24.0 statistical software (SPSS, Inc., Chicago, IL).

CHAPTER IV – MANUSCRIPT

Introduction

Physical activity participation is one of the strongest risk factors for musculoskeletal injury (Conn et al., 2003). According to the National Collegiate Athletic Association (NCAA) an average of 28.1 injuries per 1000 athlete exposures annually (Hootman, J. M., Dick, R., & Agel, 2007). Lower extremity injury represents a majority of injuries sustained during athletic participation (Fernandez et al., 2007). Recent evidence suggests severe lower extremity injury rates are increasing. For example, one study found from 1988-2004 there was a 1.3% increase in anterior cruciate ligament (ACL) injuries (Hootman, J. M., Dick, R., & Agel, 2007). Severe musculoskeletal injury, such as ACL rupture can be debilitating, requiring surgery for full repair and return to play. This can be timely and costly to both the patient and society (Cumps et al., 2008). ACL surgeries typically require 6-9 months of rehabilitation before being allowed for full return to play to sport. It was reported that surgical interventions for ACL reconstruction had an average societal cost of \$38,121. Choosing to forego surgery and complete long-term rehabilitation was reported to have an average societal cost of \$88,538 per injury (Mather et al., 2013). Thus, it is important to find preventative strategies in order to minimize risk and occurrence of ACL injuries in sport and reduce societal costs.

There are many risk factors associated with lower extremity injuries, specifically ACL rupture. Decreased range of motion has recently become a known modifiable risk factor associated with ACL injuries. Total hip transverse plane arc of motion has consistently been identified as a risk factor associated with secondary knee joint injury. One study found a link

between decreased hip internal rotation (26.4 degrees) with those who have previously suffered a non-contact ACL injury compared to those who do not (39.0 degrees) (Gomes et al., 2008). Hip extension range of motion helps aid landing and a reduced hip extension range of motion has been shown to be a risk factor for non-contact ACL injury (Shultz et al., 2015). Decreased knee flexion range of motion has been indicated as an important injury risk factor for ACL injury (Shultz et al., 2015). Along with that, decreased dorsiflexion range of motion has been shown to reduce knee flexion range of motion and thus lead to an increased risk for non-contact ACL injury (Dill et al., 2014; Fong et al., 2011). It is also important to consider whether fatigue impacts range of motion. Previous studies have observed a decrease in neuromuscular control leading to increased hip internal rotations when landing on a single leg with an induced fatigue protocol (Borotikar et al., 2008). Although we know modifiable risk factors associated with ACL ruptures, there is a need for further research on how to prevent this in the long term.

It is essential to focus on hip, knee, and ankle range of motion and how it is linked to increased risk of non-contact ACL injuries. There needs to be evidence as to whether a corrective exercise intervention can help mitigate these range of motion deficits after fatigue inducing exercise, improving risk for lower extremity injury. The purpose of this study is to determine if an intervention helps mitigate hip arc, hip extension, hamstring, great toe, and ankle dorsiflexion range of motion changes post fatigue.

Interventions to Improve Range of Motion

Based on the aforementioned literature there is an association between decreased hip motion arc, knee flexion, hip flexion, and ankle dorsiflexion and an increased risk of lower extremity musculoskeletal injury. Research should focus on improving hip, knee, and ankle range of motion in order to help prevent ACL injury in active, college-aged females.

Static Stretching

Research has evaluated static and dynamic stretching as ways to improve range of motion and ultimately improve performance. There has been evidence found to support stretching being implemented before physical activity beneficial but the effects were considered short term (Woods et al., 2007). Based on research and common knowledge of autogenic inhibition: when a muscle is put on stretch the Golgi Tendon Organs are activated and cause a sudden contraction of the agonist, then a contraction of the antagonist and relaxation of the agonist, allowing the muscle to lengthen; stretching can be useful in increasing range of motion. It is important to find an intervention to increase hip range of motion that has a lasting, long-term effect. It has been shown that static stretching regularly over a six-week time span improved plasticity of the muscle and increased range of motion ($P = .001$) (Yuktasir & Kaya, 2009). Thus, stretching is an effective tool to help improve initial range of motion but it may not be the most effective approach for long-term improvements. An integrated study needs to look at more efficient and effective procedures for improving range of motion.

Foam Rolling

There has been an increase in the literature discussing foam rolling as a means for improving range of motion and decreasing myofascial adhesions. A systematic review looked at the effects of foam rolling on hip, knee and ankle range of motion. The results showed a significant increase in hip, knee, and ankle range of motion ($P < .05$, $P < .001$, $P < .05$) respectively (Cheatham et al., 2015). Another study found foam rolling to be an effective tool to reduce delayed onset of muscle soreness and improve range of motion (Pearcey et al., 2015). Foam rolling is an option for improving range of motion, but there is not enough evidence present to determine if it is effective or efficient enough to prevent non-contact ACL injury.

Further research is needed to determine if foam rolling is enough or if there should be another approach integrated.

Deep Muscle Percussive Stimulation

It is also important to address myofascial deficits in subjects who have increased risk movement patterns for ACL injuries in order to improve range of motion. One study looked at the effects of foam rolling on myofascial release improving knee range of motion. They found significant ($P < 0.001$) results in that people who foam rolled their lower extremity gained 10 degrees of motion (MacDonald et al., 2013). Range of motion can be improved through the use of muscle inhibition and relaxation (Atha & Wheatley, 1976). The RAPTOR by Hyperice will be implemented in order to apply deep percussive stimulation to the lower extremity with each intervention in order to help release myofascial adhesions within the tissues and inhibit overactive muscles. The amount of time decreased significantly in treatment time using The RAPTOR because you only do 30 seconds to 1 minute of treatment compared to 8-10 minutes for foam rolling. It also requires less work from the clinician in that they do not have to use their thumb or put their bodies in uncomfortable positions in order to complete myofascial release treatments. There has been little to no research done on devices such as The RAPTOR so it is necessary to include this in this intervention in order to determine if there is a possibility that deep percussive stimulation along with an intervention provides significant results. This would promote further research to be done specifically for The RAPTOR so that clinicians can grasp a better understanding and knowledge base of practicing deep muscle percussive stimulation into their practice.

Intervention on Improving Range of Motion

The aforementioned evidence shows there is an increase in range of motion with different methods of intervention. Static stretching can improve range of motion through autogenic inhibition (Yuktasir & Kaya, 2009). Foam rolling can improve range of motion through inhibition of overactive muscles (Cheatham et al., 2015). Deep muscle percussive stimulation can inhibit overactive muscles (Atha & Wheatley, 1976). One systematic review reported that massage was the most effective tool in reducing markers of muscle stress, as well as compression and water immersion (Dupuy et al., 2018). There is lack of evidence on what the most effective approach is to improvements in range of motion post fatigue. Known interventions should be combined to determine if inhibiting overactive muscles, stretching overactive muscles, and activating underactive muscles can be used a form of corrective exercise intervention to be implemented post high intensity exercise exposure to mitigate range of motion changes.

Fatigue and its Effect on Range of Motion

Research has shown that fatigue alters biomechanics and range of motion in high-risk movement groups. There has been no research to focus on how fatigue affects hip arc range of motion in high-risk movers. One study looked at multiple ranges of motions for the lower extremity after a bout of fatigue induced strength training. It found significant ($P < .005$) results in increased hip flexion but did not find significant results in hip extension (Sparto et al., 1997). It has been shown that fatigue-inducing exercise can reduce ankle range of motion in active females (Christina et al., 2001). Fatiguing exercise has shown to reduce control of knee motion during landing (Orishimo & Kremenec, 2006), which can give evidence to potential changes in range of motion of the knee joint during functional testing. Further research should investigate specific changes in range of motion from baseline to post high intensity exercise exposure to

better understand the effects of fatigue on range of motion in the lower extremity.

Methods

Participants

This study consisted of 20 female subjects, 10 control subjects and 10 treatment subjects. Participants in this study were kept between 18-24 years of age. These subjects were healthy college individuals who had a history of competing in field or court sport activities and were physically active at least three times a week for thirty minutes or more. These subjects had no history of lower extremity joint surgery. These subjects had no history of lower extremity injuries in the last six months. All subjects read and signed an informed consent form approved by the Institutional Review Board of the University of North Carolina at Chapel Hill.

Instrumentation

Range of Motion

Lower extremity passive range of motion was measured with a digital inclinometer for active knee extension, hip internal rotation, and hip external rotation (Sanders Group, Inc., Chaska, MN, USA). The inclinometer was used for these ranges of motion due to reliability being more difficult (Roach et al., 2013). A standard 8-inch plastic goniometer was used to measure hip extension, hip abduction, great toe extension, straight leg ankle dorsiflexion, and bent leg ankle dorsiflexion. The inclinometer was used for these ranges of motion due to reliability being easier (Roach et al., 2013).

Integrated Recovery Intervention Program

The RAPTOR by Hyperice was used as a deep percussive muscle inhibitor to the lower extremity (RAPTOR, Hyperice[®], USA). The areas treated by the RAPTOR were medial and lateral head of gastrocnemius, lateral hamstring, hip adductors, and iliotibial band (ITB).

Procedures

All participants were randomized to either the control or treatment group. Each participant reported to the Sports Medicine Research Lab for their first session where they signed aforementioned IRB consent forms. Each participant wore her own athletic shorts and shirt. Each participant reported on the first day to complete range of motion measurements. They then completed the high intensity exercise program and had post exercise measures taken: range of motion and perceived soreness. This completed session I. After 24 hours each participant reported back for session II where they received range of motion measurements, the corrective exercise intervention or control intervention, and range of motion were taken again. Perceived recovery and soreness were taken before and after intervention and control treatments.

Range of Motion Measurements

Range of motion was taken for the dominant limb of each subject. Five values were recorded for each range of motion.

Hip Internal Rotation

Participants were asked to lay prone (face-down) on a treatment table with their hips in a neutral position and knee flexed to 90 degrees. An investigator internally rotated the participant's hip to the point of first limitation. An inclinometer was placed on the lateral surface of the participant's shank parallel to the fibula bone. The angle relative to the vertical was recorded.

Hip External Rotation

Participants were asked to lay prone (face-down) on a treatment table with their hips in a neutral position and knee flexed to 90 degrees. An investigator externally rotated the participant's hip to the point of first limitation. An inclinometer was placed on the lateral surface

of the participant's shank parallel to the fibula bone. The angle relative to the vertical was recorded.

Hip Abduction

The participant was placed in a supine position with her legs in full extension, flat on the table. One researcher stabilized the pelvis by placing a hand on the contralateral anterior superior iliac spine (ASIS) of the leg being tested then grasped the medial aspect of the shank on the leg being measured and passively abducted the leg until the point of first resistance or the participant expressed discomfort. Once this point was reached, a second researcher measured the angle with a standard goniometer with the stationary arm positioned so the distal portion was placed over the contralateral ASIS, the fulcrum over the ipsilateral ASIS, and the movement arm over the long axis of the femur, with the middle of the patella as the distal reference.

Hip Extension

The participant was positioned in a supine position with hip joint positioned over the edge of the table. The participant brought both knees to chest and held this position while the low back, sacrum, and pelvis remained horizontal and were stabilized by the investigator; the participant then relaxed dominant limb which allowed the knee to flex and the thigh to drop down towards the table into the investigator's hand until the point of first resistance was felt by the investigator with the anterior-superior iliac spine being felt to rotate anteriorly. Once the investigator identified this point, a second researcher measured the angle with a goniometer along the lateral aspect of the thigh at the midpoint along a line between the test limb greater trochanter and lateral femoral epicondyle.

Ankle Dorsiflexion Straight Leg

The participant was placed in a supine position with both legs fully extended, the contralateral leg flat on the table and the leg tested propped on a bolster placed at the mid-shaft of the tibia. The investigator stabilized the shank by grasping the tibia/fibula at mid-shaft and grasped the foot with the opposite hand and passively moved the foot into dorsiflexion until the point of first resistance or the participant expressed discomfort. Once this point was reached the investigator measured the angle with a standard goniometer with the stationary arm aligned with the long axis of the fibula and the fulcrum and the movement arm aligned with the long axis of the fifth metatarsal.

Ankle Dorsiflexion Bent Leg

The participant was placed in a supine position with both legs propped on a box, leg tested propped on a bolster placed at the mid-shaft of the tibia. The investigator stabilized the shank by grasping the tibia/fibula at mid-shaft and grasped the foot with the opposite hand and passively moved the foot into dorsiflexion until the point of first resistance or the participant expressed discomfort. Once this point was reached the investigator measured the angle with a standard goniometer with the stationary arm aligned with the long axis of the fibula and the fulcrum and the movement arm aligned with the long axis of the fifth metatarsal.

Great Toe Extension

The participant was placed in a supine position with both legs fully extended, the contralateral leg flat on the table and the leg tested propped on a bolster placed at the mid-shaft of the tibia. The investigator stabilized the foot and passively moved it into dorsiflexion until the foot was in a neutral position (~0 degrees of dorsiflexion). Once this point was reached the investigator passively extended the great toe until the point of first resistance or the participant

expressed discomfort. At this point the investigator measured the angle with a standard goniometer, with the stationary arm aligned parallel to the first ray, the fulcrum centered over the 1st metatarsal-phalangeal joint, and the movement arm placed parallel to the long axis of the 1st metatarsal.

Fatigue Protocol

Each subject was taken to The Exercise Oncology Research Laboratory where they completed the $VO_{2\text{sub-max}}$ and VeT assessment. The Exercise Oncology Research Laboratory was located 25 feet from The Sports Medicine Research Laboratory. Upon arrival to The Exercise Oncology Research Laboratory each subject sat resting in a chair for 5 minutes at which point a member of the research team placed a heart rate monitor around their chest and explained the assessment protocol. Their resting vitals were assessed and a research team member confirmed they did not have restrictions from high-intensity exercise. After vitals and unrestricted exercise participation were determined, each subject was fitted with a breathing mask to measure breathing gasses during the assessment. They each had 3-5 minutes to get used to breathing through the mask, then performed a 5 minute warm-up on the treadmill at 4.0 mph. After the warm-up the test began using 1-minute stages that began at a speed of 5.0 mph. Each stage increased by 1.0 mph until a speed of 8.0 mph (3rd minute – Stage #4). After the treadmill speed increased to 8.0 mph, each successive 1-minute stage increased speed by 0.5 mph. The test was complete when they reached termination criteria including voluntarily stopping by informing the researchers. Each subject completed the high-intensity exercise protocol exactly 10 minutes after completing the above fitness assessment. The protocol started with each subject running at a speed that was coincident with ~75% of their maximal aerobic capacity. This exercise intensity represented an exercise intensity that was difficult but not near maximal intensity and was a

speed that could be maintained for a short distance run (~1 mile), but could not be sustained for longer duration activity. They each ran on the treadmill for 5 minutes, then stepped off the treadmill and performed ten back-to-back jump-landings and 10 split squats (5 on each leg). They each then completed a total of 5 sets of the 5 minute running and 10 jump-landing and 10 split squat intervals. After the final jump landing and split squat interval they rested for 3 minutes and then completed 10 more jump landings, 20 split squats (10 each leg) two times. By the end of the high-intensity exercise exposure, each subject performed 70 total jump-landings and 90 split squats (45 each leg) which took approximately 20 minutes to complete; 45 minutes all together with the running.

Corrective Exercise Intervention

Each participant completed one session of the corrective exercise intervention program twenty four hours post acute high intensity exercise exposure. The intervention consisted of inhibition of overactive muscles, static stretching of overactive muscles, isolated activation of underactive muscles, and an integrated functional exercise. Overactive muscle inhibition was accomplished using the RAPTOR, focusing on the calf, ITB, hip adductor complex, and lateral hamstring for two minutes at each muscle site bilaterally. Each participant then completed static stretching focusing on the calf, ITB, hip adductor complex, and lateral hamstring for 2X30 seconds. For the static calf stretch they faced a wall in a staggered leg position, leaned against the wall and pushed their lower leg back until a noted stretch was felt in the calf. For the ITB each participant positioned themselves parallel to the wall, pushed their involved hip towards the wall while they stabilized their uninvolved leg in front. For the hip adductors each participant was positioned standing with the uninvolved limb stabilizing in a flexed position while the involved limb reached out to the side away from the body. For the lateral hamstrings each

participant was supine on the floor with the uninvolved limb straight out and involved leg hip flexed and adducted keeping the leg straight. Each participant then completed isolated activation of underactive muscles: heel raise 2X10, sidelying hip abduction 2X10, double leg hip bridge 2X10. Finally, each participant then completed functional exercise to incorporate all previously completed components: side step down 2X10, double leg to single leg stabilization 2X10.

Session I

Each participant reported to the Sports Medicine Research Lab for session I where they received pre exercise assessments that included specific gravity, resting heart rate, blood pressure, height, and weight. They then had range of motion measures taken as described above. Once the pre assessments were completed each participant completed the high intensity exercise exposure as previously described. Upon completion of the high intensity exercise exposure range of motion was taken again along with perceived soreness and recovery scales. Each participant was then sent home for 24 hours where they were instructed to not exercise until the end of testing.

Session II

Each participant then reported back twenty four hours post session I to complete session II. After arrival for session II each participant completed perceived soreness forms and had range of motion measures taken. They then completed their respective treatment sessions. Those in the control group had an electrical stimulation unit applied but not turned on and then had range of motion measures taken post and perceived soreness forms. Those in the corrective exercise intervention group completed the full corrective exercise intervention and then had range of motion measurements taken and perceived soreness forms. All subjects were then done with their respective sessions and were free to leave.

Statistical Analysis

Each range of motion was taken five times at each time point. An average was taken of all five trials to determine an average for each time point. Change scores were calculated between post-24 hours and post-intervention range of motion values between a control group and corrective exercise intervention group. Independent samples t-tests were carried out to evaluate the effects of the intervention on changes in range of motion between post-24 hours and post-intervention time points. Statistical significance was set at $\alpha < 0.05$. All data were analyzed using SPSS 24.0 statistical software (SPSS, Inc., Chicago, IL).

Results

There was a significant difference in the change score between the intervention group and control group ($p = .047$) (Table 1). Specifically, the change in hamstring range of motion was greater in the intervention group compared to the hamstring range of motion in the control group (Effect Size = 0.95). Furthermore, inspection of the 95% confidence interval of the change scores revealed no change in hamstring range of motion for the control group as the upper and lower bounds included zero. However, there was a meaningful change for the intervention group, as the 95% confidence interval values did not include zero.

In addition, there were no other significant differences in change scores between the intervention group and control group ($p > 0.05$) (Table 2). Additionally the 95% confidence interval values for all other change scores enveloped zero for both intervention and control groups, which indicate no meaningful change in any of the range of motion values.

Discussion

This study investigated the effects of an acute recovery intervention on muscle extensibility. The most important finding of this study was that the acute recovery corrective

exercise intervention improved knee extensibility and hamstring range of motion as compared to those in the control group from time points pre-intervention to post-intervention twenty four hours after high intensity exercise exposure. There were no changes observed in the control group from pre-intervention to post-intervention. This study found no effects of the acute recovery intervention on straight leg ankle dorsiflexion, bent leg ankle dorsiflexion, hip internal rotation, hip external rotation, hip extension, or hip abduction. Thus, it has been shown that knee extensibility and hamstring range of motion can be improved in active females when a corrective exercise intervention is implemented twenty-four hours post fatigue inducing exercise.

These findings are important because they reveal that an acute recovery intervention can change knee extensibility range of motion after fatigue exposure, which may be important to implement into clinical practice. Previous findings have observed and increase in knee extensibility, hamstring range of motion, and lower extremity range of motion after implementation of an intervention such as stretching, foam rolling, or massage (Cheatham et al., 2015; Dupuy et al., 2018; Mohr, Long, & Goad, 2014; Pearcey et al., 2015). The findings from this study are novel in that it was applied specifically twenty-four hours post fatigue.

This finding for improvement in hamstring range of motion can most likely be attributed to the focus of the corrective exercise intervention, which would also explain the lack of change for other joints that were measured. The corrective exercise intervention used The Raptor by Hyperice to apply inhibitory vibrations to overactive muscles. The primary muscle groups targeted for The Raptor application were the lateral head of the gastrocnemius complex, lateral hamstrings, adductors, and iliotibial band. These muscles all cross over the knee joint so when targeted together provided the most inhibition to hamstring range of motion in the form of active knee extension. In addition the main muscles targeted for stretching in the corrective exercise

intervention were the gastrocnemius complex, the lateral hamstring, adductors and the iliotibial band. There were four muscles targeted with The Raptor that all cross the knee joint, thus the main motion to be improved would be knee extension. Inhibiting and stretching these overactive muscles that all cross over the knee joint provided the hamstring with the most improvement in range of motion. Also, the main exercises used in the corrective exercise intervention were side lying leg raise, glute bridges, lateral step downs, and double leg to single leg hop to stability, which were all gluteal focused exercises. During hip extension it is important to allow the gluteal muscles to activate before the hamstring muscles in the prevention of injury (Chance-Larsen, Littlewood, & Garth, 2010). By completing gluteal focused exercises the corrective exercise intervention allowed to gluteal muscles to activate and allow the hamstring musculature to be inhibited (Chance-Larsen et al., 2010). Other studies focused on inhibiting hamstring muscles using other forms of recovery such as foam rollers or roller bars also found similar findings in improvement of hamstring range of motion (Cheatham et al., 2015). Mohr et al found that when combined, stretching and foam rolling was associated with an improvement in range of motion at the hip (Mohr et al., 2014). One systematic review reported that massage was the most effective intervention in reducing markers of muscle stress (Dupuy et al., 2018), which is similar to foam rolling and vibration in that massage inhibits overactive muscles. Another study found foam rolling to be an effective recovery tool to improve range of motion (Pearcey et al., 2015). It has been shown that static stretching regularly over a six-week time span improved plasticity of the muscle and increased range of motion ($P = .001$) (Yuktasir & Kaya, 2009). The findings of the aforementioned studies coincide with results found for hamstring range of motion and knee extensibility in this experiment with other articles focusing on foam rolling and stretching as recovery tools post fatigue-inducing exercise. This study showed significant improvements in

hamstring range of motion post fatigue inducing exercise for the intervention group, which is similar to what other studies have found for recovery interventions (Cheatham et al., 2015; Mohr et al., 2014; Pearcey et al., 2015; Yuktasir & Kaya, 2009). Other studies have found improvements in range of motion of the lower extremity. However, not all of these studies looked at the effects of foam rolling and stretching at a specific time point post fatigue inducing exercise. This intervention was most likely successful for improving hamstring range of motion through the use of relaxation and inhibition of the overactive musculature (Atha & Wheatley, 1976). In addition, allowing a stretch of the overactive muscles improved flexibility through relaxation of muscle fibers (Herbert & Gabriel, 2002). However, most studies found improvements for all muscle groups targeted for their intervention. This study only observed improvements in hamstring range of motion. The other joints and muscle groups targeted in this study most likely did not show improvements based on what was targeted most through the intervention as previously mentioned. The ankle joint only had one muscle, lateral gastrocnemius, targeted with The Raptor. The plantar aspect of the foot and hip external rotators were never targeted with The Raptor. The hip internal rotators and adductors were only targeted one time with The Raptor. The stretches focused on were specific the hamstring, IT Band, and calves, whereas there should have been more hip internal and external stretches included. In addition, exercises should have been tailored to multiple body parts to include the gastrocnemius-soleus complex and the hip.

This study has found statistically significant results for a one time implemented corrective exercise intervention twenty-four hours post fatigue inducing exercise. Further research should focus on targeting muscle groups multiple times with inhibition, stretching and activation in order to improve other joints ranges of motion. Also, further research should focus

on implementing this corrective exercise intervention over a multi week time period to determine results of consistent use in active females.

TABLES

Table 1: Change Scores on the Effect of a Corrective Exercise Intervention Group vs. Control Group on Range of Motion Twenty-Four Hours Post Fatigue Inducing Exercise

Range of Motion	Control Group Change			Intervention Group Change			Difference	95% CI on Difference	P-Value	Effect Size
	mean	(SD)	95% CI control group	mean	(SD)	95% CI Intervention group				
Abduction	0.9	4.3	[-1.42, 3.92]	1.4	2.6	[-0.27, 3.0]	-0.5	[-3.83, 2.91]	0.78	0.13
Extension Hamstring	0.6	1.9	[-0.5, 1.74]	0.9	1.2	[0.11, 1.67]	-0.2	[-1.72, 1.26]	0.75	0.15
90/90	0.5	2.6	[-1.32, 1.86]	-2.1	2.9	[-4.16, -0.5]	2.6	[0.04, 5.13]	0.05	0.95
Hip Internal Rotation	0	3.3	[-2.03, 2.1]	-0.1	3.9	[-2.3, 2.62]	0.1	[-3.31, 3.43]	0.97	0.02
Hip External Rotation	-2.4	4.1	[-4.99, -0.06]	0.9	4.6	[-1.8, 4.02]	-3.3	[-7.4, 0.78]	0.11	0.76
SL Dorsiflexion	1.2	1.4	[0.33, 2.02]	1.9	1.9	[0.76, 3.0]	-0.7	[-2.25, 0.85]	0.35	0.43
BL Dorsiflexion	0.1	1.5	[-0.68, 1.05]	0.2	1.6	[-0.78, 1.16]	-0.1	[-1.5, 1.37]	0.93	0.04
Great Toe Extension	-0.2	3.4	[-1.98, 2.1]	0.3	5.1	[-2.29, 4.02]	-0.5	[-4.61, 3.53]	0.78	0.12

Table 2: Raw Mean Values of Range of Motion Pre and Post Intervention for Intervention and Control Groups

Range of Motion		Pre		Post	
		mean	(SD)	mean	(SD)
Abduction	Control	39.4	5.0	40.3	4.7
	Intervention	40.0	5.6	41.5	6.6
Extension	Control	-3.8	6.4	-3.2	6.9
	Intervention	-2.2	3.1	-1.3	3.2
Hamstring 90/90	Control	61.4	7.9	61.9	6.4
	Intervention	62.4	7.3	60.3	7.4
Hip Internal Rotation	Control	39.2	8.4	39.2	6.9
	Intervention	43.2	8.1	43.1	8.9
Hip External Rotation	Control	44.4	5.6	42.0	5.4
	Intervention	44.4	11.0	45.3	9.3
SL Dorsiflexion	Control	-3.5	4.4	-2.3	3.5
	Intervention	-1.7	3.6	0.2	4.2
BL Dorsiflexion	Control	6.9	3.4	7.0	3.6
	Intervention	9.4	2.9	9.5	3.6
Great Toe Extension	Control	78.0	5.7	77.8	4.5
	Intervention	79.2	11.4	79.5	11.7

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CHAPTER V

Statistical Analysis

Each range of motion was taken five times at each time point. An average was taken of all five trials to determine an average for each time point. A three by two repeated measures ANOVA was used to determine the differences in range of motion between a control group and a corrective exercise intervention group over three time points: pre-fatigue, immediately post-fatigue, 24 hours post-fatigue. Statistical significance was set at $\alpha < 0.05$. A Tukey post hoc analysis was used for significant results. All data were analyzed using SPSS 24.0 statistical software (SPSS, Inc., Chicago, IL).

Results

There was a significant difference within time points for hamstring range of motion ($p = .02$) (Table 3). Specifically there was a decrease in hamstring range of motion from baseline, post-0 fatigue and post-24 fatigue. Tukey Post Hoc analyses were performed and demonstrated that hamstring range of motion immediately post fatigue was significantly reduced compared to pre-fatigue ($p = .002$) (Graph 1). However, there were no differences between twenty four hours post fatigue and pre-fatigue measures ($p = .137$) or immediately post fatigue ($p = .253$) measures.

However, there were no significant group by time interactions ($P > .05$) or any other main effects for time ($P > .05$) for the remainder of the range of motion variables. These findings indicate that range of motion immediately following and twenty-four hours post the fatiguing bout of exercise were not significant different than before fatigue with the exception of hamstring range of motion.

Discussion

Reliability was established between two investigators (Table 4, 5). Although two different researchers took range of motion measurements inter rater reliability was established (Table 6). Thus, there should be no difference in range of motion outcomes based on which investigator collected the data.

We observed a decrease in knee extensibility and hamstring range of motion immediately post-fatigue but not twenty-four hours post-fatigue. Overall, we did not observe a change across muscle groups. This could potentially be related to viscoelasticity increasing due to tissue warming (McHugh, Magnusson, Gleim, & Nicholas, 1992). This thixotropic increase may have offset any other changes from happening (Proske, Morgan, & Gregory, 1993). There were most likely minimal changes for group by time and time for range of motion based on the baseline values for subjects across the board. The mean averages of subjects at baseline were lower than what normative values are. Based on this, from pre-fatigue to post-fatigue and twenty-four hours post fatigue there is no room for range of motion to decrease more. Further research should establish normative range of motion values for athletes. A possible explanation for why we saw a change in only hamstring range of motion would be how many muscles were targeted in in the fatigue protocol that cross the knee joint. The amount of running and then jump landings and split squats performed would cause an increase in the stretch shortening cycle and both eccentric and concentric contractions of the hamstrings multiple times, which create a decrease in hamstring range of motion and knee extensibility (Jonhagen, Nemeth, & Eriksson, 1994).

Although we did see a decrease in hamstring range of motion from pre-fatigue to post-fatigue it may not be clinically significant. There was a three degree shift in range of motion, which is under the minimal clinically important difference, ten degrees, of hamstring range of

motion and knee extensibility (Shamus & Email, 2003). Further research should focus on how this fatigue protocol could be modified to target other muscles of the body to include the gastrocnemius complex, hip internal and external rotators, hip flexors, and hip adductors.

TABLES

Table 3: Change in Range of Motion over Three Time Points (Baseline, Post-0 Fatigue, Post-24 Fatigue) Within Groups

Range of Motion		Pre		Post-0		Post-24		P-Value	
		mean	(SD)	mean	(SD)	mean	(SD)	Group*Time	Time
Abduction	Control	40.8	4.4	37.7	5.0	39.4	5.0	0.18	0.64
	Intervention	39.2	6.1	40.3	4.6	40.0	5.6		
Extension	Control	-4.2	6.8	-2.9	5.6	-3.8	6.4	0.16	0.51
	Intervention	-1.5	3.4	-2.0	2.9	-2.2	3.1		
Hamstring 90/90	Control	60.9	5.2	62.9	6.7	61.4	7.9	0.44	0.02
	Intervention	59.4	7.2	63.3	6.1	62.4	7.3		
Hip Internal Rotation	Control	41.0	5.1	44.5	4.9	39.2	8.4	0.28	0.16
	Intervention	43.8	9.4	43.9	7.5	43.2	8.1		
Hip External Rotation	Control	41.1	6.3	42.5	6.6	44.4	5.6	0.69	0.31
	Intervention	43.4	12.1	44.0	9.3	44.4	11.0		
SL Dorsiflexion	Control	-3.4	2.3	-2.9	2.9	-3.5	4.4	0.64	0.32
	Intervention	-0.6	3.4	-0.2	4.7	-1.7	3.6		
BL Dorsiflexion	Control	7.5	3.9	7.4	4.0	6.9	3.4	0.48	0.85
	Intervention	9.1	3.7	8.6	2.7	9.4	2.9		
Great Toe Extension	Control	78.4	6.7	77.3	4.9	78.0	5.7	0.59	0.63
	Intervention	80.5	12.9	80.4	12.2	79.2	11.4		

Table 4: Intra Rater Reliability for Investigator #1

Assessment	ICC value	Sdpre	Sdpost	Pooled SD	SEM
Abduction	0.984	7.6	7	7.31	0.92
Hip Extension	0.984	4.8	4	4.42	0.56
Hamstring 90/90	0.958	10.8	9.7	10.26	2.10
Hip Internal Rotation	0.982	10	11	10.51	1.41
Hip External Rotation	0.918	6.5	6.1	6.30	1.80
Straight Leg Dorsiflexion	0.988	3.6	4.1	3.86	0.42
Bent Leg Dorsiflexion	0.86	3.6	3.1	3.36	1.26
Great Toe Extension	0.952	8.5	7.1	7.83	1.72

Table 5: Intra Rater Reliability for Investigator #2

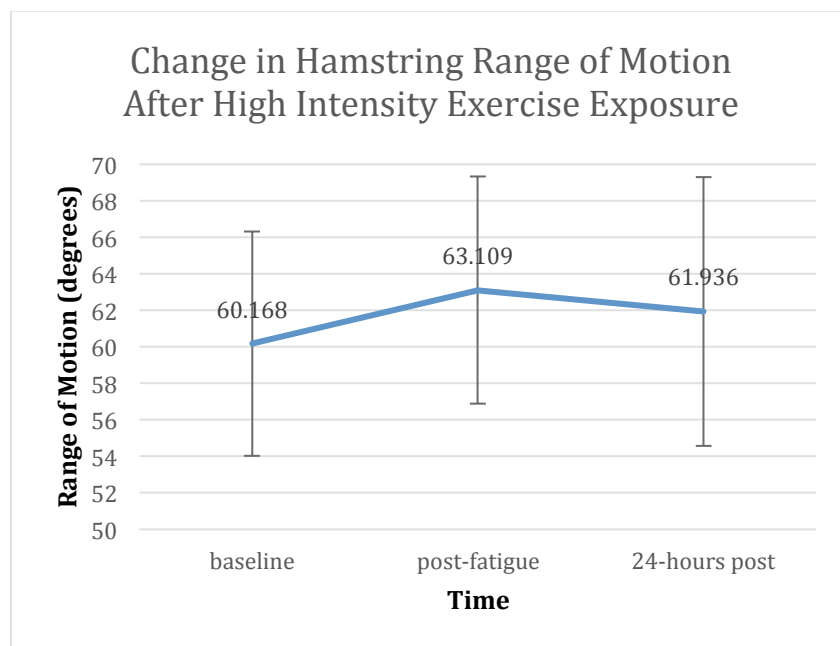
Assessment	ICC value	Sdpre	Sdpost	Pooled SD	SEM
Abduction	0.912	3.5	3	3.26	0.97
Hip Extension	0.877	2.5	3	2.76	0.97
Hamstring 90/90	0.887	5.7	6.2	5.96	2.00
Hip Internal Rotation	0.947	8.9	8.6	8.75	2.01
Hip External Rotation	0.898	6	4.4	5.26	1.68
Straight Leg Dorsiflexion	0.979	4	4.2	4.10	0.59
Bent Leg Dorsiflexion	0.992	4.1	4.6	4.36	0.39
Great Toe Extension	0.928	9.4	9.1	9.25	2.48

Table 6: Inter Rater Reliability Between Investigator #1 and #2

Assessment	ICC value	Sdpre	Sdpost	Pooled SD	SEM
Abduction	0.843	5.7	4.9	5.32	2.11
Hip Extension	0.848	2.5	2.3	2.40	0.94
Hamstring 90/90	0.95	5.1	5.7	5.41	1.21
Hip Internal Rotation	0.93	7.7	8.9	8.32	2.20
Hip External Rotation	0.912	6.5	6.8	6.65	1.97
Straight Leg Dorsiflexion	0.879	3.4	4	3.71	1.29
Bent Leg Dorsiflexion	0.935	2.8	2.9	2.85	0.73
Great Toe Extension	0.83	6.9	11.8	9.67	3.99

GRAPHS

Graph 1: Change in Hamstring Range of Motion After High Intensity Exercise Exposure



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