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A Two-Hour Basketball Practice Increases Landing Error Scoring System Scores in Female Collegiate Basketball Players

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ABSTRACT

The high rate of knee injuries in women's athletics has been well documented in recent years. There are multiple factors which contribute to the increased risk of injury in female athletes, including biomechanics when landing. Fatigue has also been examined as a contributing factor to injury, but few studies have utilized actual sport participation as a fatiguing protocol. No study has used the Landing Error Scoring System (LESS) to examine the changes that may result from fatigue. The objective of our study was to use the LESS to examine the effects of a two-hour basketball practice on the landing biomechanics of female collegiate basketball players. A 2x2 repeated measures design was utilized in our study. The independent variables were time (pre-intervention and post-intervention) and session (experimental and control). Subjects (n=10) participated in two counterbalanced data collection sessions in the Lynchburg College gymnasium. The order of the sessions was determined randomly, and sessions were separated by approximately three days. Six athletes performed the experimental procedure first, while four performed the control procedure first. The experimental session consisted of a series of five drop landings from a height of 32 cm, the basketball practice of the day (approximately two hours in duration), and another series of five drop landings. The control session consisted of five drop landings, a rest period of two hours, followed by another five drop landings. Subjects were given no instruction on how to land, and were videotaped from the neck down during all drop landings. The subject's assigned group was blinded while scoring the landings to decrease biasing. Ten healthy, National Collegiate Athletic Association (NCAA) division three women's basketball athletes (age=18.95±0.31 years, height=171.2±10.52 cm, mass=65.86±11.55 kg) volunteered to participate in the study. Subjects were required to be free of lower extremity injury and/or surgery in the previous 12 months, be able to perform a drop jump without pain, and be able to participate fully in basketball practice. The dependent variable was the LESS score for each drop jump. The LESS uses video feedback to grade landings based on 15 biomechanical factors. Pre- and post-intervention as well as pre- and post- control LESS scores were compared using a 1x2 repeated measures ANOVA. The *a priori* alpha level was set at $P \leq 0.05$. LESS scores significantly increased from pre-intervention (6.088±1.887) to post-intervention (6.889±2.230) (P=.028). There was no significant difference from precontrol scores (6.200±1.364) to postcontrol scores (6.422±1.321). ($F_{1,8}=1.562$, $P=.247$, $n^2=.163$, $1-\beta=.653$). Increased LESS scores may predict an increased risk of ACL injury. Fatigue may play a role in altering landing biomechanics, causing an individual to land less efficiently. This may place the ACL at a higher risk of injury.

REVIEW OF LITERATURE

I. Epidemiology and Demographics

Anterior cruciate ligament (ACL) ruptures are debilitating knee injuries that are often season-ending.[1] Surgery and rehabilitation of ACL ruptures are costly, with estimates of expenses between $17,000 and $25,000 per injury.[2] It is estimated that 7,000 ACL ruptures occur in female high school basketball players each year; this would amount to an annual cost of up to $119 million for reconstruction and rehabilitation of ACL injuries in this group alone.[2] In addition to the monetary cost, individuals experiencing ACL injury are faced with the possibility of losing an entire season of sports participation. This emotional stress that accompanies ACL injury has been associated with lowered academic performance in collegiate athletes.[3] Additionally, ACL injury places the individual at a risk of developing future complications related to the injury including long-term disability and osteoarthritis.[3-7]

Many studies have demonstrated the gender disparity in the risk of ACL injury, and found that female athletes are 2-6 times more likely to sustain an ACL rupture than male athletes participating in the same sports.[3, 5, 6, 8-10] Actual ACL injury rates are determined through data obtained from the National Collegiate Athletic Association (NCAA) Injury Surveillance System (ISS), a database of injury information and trends collected from a representative sample of NCAA Division I, II, and III institutions located throughout the United States. An exposure is defined as "the participation of one athlete in one practice or game where he or she is exposed to the possibility of athletic injury.[8]" The value which results is the injury rate, expressed as "injuries per 1000 athlete exposures.[8]" Statistical significance is set at $P<0.05$for injury rates obtained through the ISS.[5, 6, 8, 11]

Noncontact ACL injuries in Division I collegiate basketball players were tracked during the 1988-89 and 1989-90 seasons. Females suffered ACL injuries at a rate 6.1 times that of men.[10] Injury data were again collected from the years 1989-1993 for men's and women's soccer and men's and women's basketball.[8] The ACL injury rate for female basketball players was 0.29, more than four times the 0.07 injury rate of male basketball players. Injury data from soccer showed a similar disparity; the ACL injury rate for women was found to be 0.31 and only 0.13 for men. From 1990 through 1998, ISS data revealed that female basketball players experienced 2.89 times the ACL injuries of male basketball players, and female soccer players sustained 2.29 times more ACL injuries than male soccer players.[6] A second collection of ISS data from 1994-1998 again revealed an increased rate of ACL injury in females.[5] The rate of injury for women was 0.30, while only 0.10 for men, and in soccer, 0.33 for women and 0.12 for males.[5]

The most recent gender comparison of ACL injury rates uses ISS data from 1994-2004 for the sports of men's and women's basketball, men's and women's soccer, and men's and women's lacrosse.[11] Over this time period, female basketball players experienced ACL injury at a rate of 0.28, as compared to the 0.08 rate of male basketball players. Anterior cruciate ligament injury occurred in female soccer players at a rate of 0.32, as compared to a rate of 0.11 for male soccer players. Men's and women's lacrosse players are alike in their injury rates, 0.17 and 0.18 respectively. However, it was noted that it is difficult to make comparisons between these two sports because of differences in the rules of play and in the amount of contact permitted. Such differences do not exist between men's and women's soccer or men's and women's basketball.

The gender disparity in ACL injury is also present at the high school level.[1, 4, 12, 13] A study of basketball players in Texas high schools found females' risk of knee injury to be significantly (2.1 times) higher than male basketball players.[12] Although males sustained more total injuries, female basketball players experienced 3.75 times more ACL injuries per exposure hour. The risk of injury for both genders increased during games as compared to practices.[12] These findings are supported by a study of New Jersey high school basketball players which found the ACL injury rate for females to be 3.52 times that of males.[4]

II. Risk Factors for ACL Injury

In considering the incidence of a particular injury, it is necessary to determine the factors that predispose an individual to the injury, and which of these can be altered to decrease an individual's risk. Factors may be intrinsic (those which cannot be altered), extrinsic (those which can be altered), or a combination of the two (partially controllable). Intrinsic factors include hyperextension of the knees, physiologic rotary laxity, size of the ACL, size and shape of the femoral notch, hormonal influences, and inherited skills and coordination. Extrinsic factors include strength, conditioning, shoes, and motivation. Factors that can be modified to some extent include proprioceptive abilities, neuromuscular activation patterns, order of muscle firing, and acquired skills.[6] Landing biomechanics are also considered modifiable; they can be altered to some degree by instruction and training programs.[6]

Intrinsic and extrinsic factors were examined through a prospective four-year study of new cadets at the United States Military Academy.[14] Although males experienced a higher rate of ACL injury, noncontact ACL tears occurred more often in females than males at a 3:1 ratio.[14] The study also found several intrinsic factors, including narrower notch width and generalized joint laxity, and extrinsic factors, such as body mass index (BMI) to be present in females who sustained a noncontact ACL injury. Subjects who had more than one of these factors were at an increased risk. Perhaps the most significant finding of this study was that women with generalized joint laxity had a 2.7 times greater risk of ACL injury than those without laxity.[14]

Understanding the mechanism of injuries that occur in sport is also necessary in the design of intervention programs to reduce the risk of such injuries. There is consensus in the literature that approximately 70% of ACL injuries are noncontact in nature.[9, 15, 16] A noncontact ACL rupture is defined as occurring in the absence of a direct blow to the knee.[9, 16] Anterior cruciate ligament ruptures that occur in situations of body-to-body contact without a direct blow to the knee are termed "noncontact injuries with perturbation.[17]" These mechanisms of injury have been discovered through the use of videotapes[9] and survey questionnaires.[15] Video analysis was used to record women's team handball practices and games. Findings revealed that the mechanism of injury for an ACL rupture most often involved a valgus collapse at the knee combined with tibial rotation and minimal knee flexion. Most injuries involved planting and cutting on a one-legged landing.[9] One study utilized questionnaires and discovered similar findings; most ACL injuries in females involve a deceleration force with little knee flexion.[15]

The most common mechanism of noncontact ACL injury in basketball has been described as the "position of no return," in which the back is forward flexed and rotated to the opposite side, the hips are abducted and internally rotated, the knees are less flexed and in a valgus position, and the tibia are externally rotated.[6] The athlete lands out of control and/or on one foot, with weight forward on the balls of the feet. This position places a great amount of stress on the ACL, as the actions of the gluteus maximus and hamstring muscles (which usually have a synergistic action with the ACL) are unable to protect it.[6] Other studies[6, 9, 18] support the majority of these findings: the highest load is placed on the ACL when there is reduced knee flexion, increased knee valgus, and tibial external rotation on a planted foot; individuals who land with these characteristics are at higher risk for ACL injury than those who do not.

III. Gender Differences During the Drop Jump Task

The landing technique of an athlete is critical, as it determines how the force of the landing is distributed throughout the body.[19] Much evidence has been gathered to support that one of the most common mechanisms of noncontact ACL injury involves a landing (deceleration) force, small amounts of knee flexion, and a valgus collapse at the knee joint.[6, 9, 15, 17] Epidemiological studies have demonstrated that female athletes are at a higher risk for ACL injury than male athletes.[2-6] Much research has been devoted to gender differences in neuromuscular and biomechanical characteristics during landing. Studies have been conducted which have utilized videographic analyses to determine landing strategies in both males and females.[1, 13, 18, 20, 21]

Video recording and the LESS are common tools used in the evaluation of drop vertical jump tasks.[1, 13, 16, 18, 20-23] The drop vertical jump has been shown to have strong within-session reliability with intraclass correlation coefficients of greater than 0.93.[24] This is a planned task that is relatively simple to perform. The subject stands on top of a plyometric box, drops down directly off the box, and immediately after landing, performs a maximum vertical jump with both arms in the air as if jumping to rebound a basketball. The height of the box and number of jumps performed vary among studies.[1, 13, 16, 18, 20-23] In many studies,[1, 13, 16, 20] subjects land on force platforms embedded into the floor so that each foot contacts one platform; this can be done to evaluate ground reaction forces of the landings. Increased ground reaction forces when landing indicate that the body is not effectively absorbing the force of the landing; some suggest that this may be a factor in ACL injury.[16, 17]

Another variable that has been measured through the drop jump is joint separation of the hips, knees, and ankles;[25] a software program was used to measure centimeters of absolute separation between a subject's right and left joints. The distance is indicative of the athlete's ability to control lower limb alignment; for example, a lower amount of separation between the knees (i.e. an increased valgus angle) could potentially lead to a higher risk of ACL injury.[25] Contrary to previous studies,[1,13,26] no significant difference was found regarding the amount of overall knee separation of the femur and tibia of males and females. However, it was discovered that during takeoff (the time frame in which the athlete's body initially moves upward), a decrease in knee separation was present in 80% of female athletes.[25] This suggests that females have problematic muscle activity and biomechanics from the start of a jump.[25]

Analysis of a single leg drop landing task from a height of 60 cm has also been used to evaluate gender differences in valgus knee angles when landing.[26] A motion analysis system was used to find that at initial contact, women landed in greater knee valgus than men. This suggests that women may be "preprogrammed" with poor landing strategies, placing them at higher risk of ACL injury than men.[26] Limiting the amount of valgus force on the knee during landing may reduce the occurrence of noncontact ACL injury.[26]

A prospective study was conducted using drop jumps from a height of 31 cm onto two force plates to evaluate female soccer, basketball, and volleyball athletes.[16] Subjects performed the drop jumps before their respective seasons; landing biomechanics were then analyzed using 3-dimensional software. During the season, certified athletic trainers employed at the subjects' schools submitted weekly exposure and injury reports to the researchers. An exposure was defined as one athlete's participation in one practice or one game. During the season, 9 athletes experienced an ACL rupture. These 9 had significantly different knee landing posture and loading characteristics than athletes who did not sustain an ACL injury, including greater dynamic knee valgus angles, greater knee abduction angles at initial contact, less maximal knee flexion, 20% higher ground reaction force, and 16% shorter stance time. Subjects who landed with this combination of characteristics subject their knees to high amounts of torque and force in a short amount of time; their ACL may not be able to sustain such loads. Additionally, females who injured the ACL possessed significant leg-to-leg differences in knee loading. A subject was found to be 6.4 times more likely to injure her ACL if her knee abduction movements were different bilaterally.[16] The study stated that biomechanics observed during a drop jump task, such as increased valgus motion and valgus moments at the knee, can predict the potential for an increased risk of noncontact ACL injury in female athletes with high sensitivity (78%) and specificity (73%).[16]

A comparative study of male and female high school basketball players used a two-dimensional video to analyze landing strategies. An additional 3 cm of valgus knee motion was measured in females' knees as compared to males' knees.[13] A second study of this population found that female athletes landed with more maximum valgus angles and total valgus motion than male athletes.[1]

There are several possibilities for the gender difference in landing techniques, including ligament dominance, limb dominance and altered neuromuscular characteristics of the lower extremity.[1] Ligament dominance results from an inability of the athlete's musculature to control forces exerted on the lower extremity during a sports activity. Because the muscles are incapable of preventing the unwanted torque, ligaments must absorb the additional stress in order to control joint movement. When too much force is placed on a ligament, it may rupture.[1] A higher amount of valgus movement observed during a sport movement reflects the inability of an athlete's musculature to control ground reaction forces.[2] Athletes with high amounts of valgus motion and valgus angles place stress on their ACL.[1]

Limb dominance indicates an imbalance between sides of the body, which can influence landings. Female basketball players have been found to land with increased valgus knee angles in their dominant leg as compared to their nondominant leg.[1] The presence of limb dominance has the potential to increase the risk of ACL injury in either knee. As the dominant leg is relied upon in higher force situations (for landing and shock absorption) it is more likely to experience torques high enough to cause the ACL to tear. Conversely, the nondominant limb may have a decreased ability to stabilize itself against moderately sized torques. Thus, muscle imbalance resulting from limb dominance may increase a subject's risk of ACL injury.[16]

Such discrepancies may originate in the teenage years.[20, 27, 28] A longitudinal study[20] examined the effects of puberty on healthy adolescent and preadolescent male and female athletes from middle and high schools. Pubescent boys experienced increases in vertical jump height with maturation, whereas girls of the same age did not. As female athletes matured, they demonstrated higher ground reaction forces and higher loading rates as compared to maturing boys. In other words, the females failed to improve neuromuscular performance as they grew. This failure to experience neuromuscular adaptations to accompany a growth spurt has been cited as a potential cause for females' higher risk of ACL injury after puberty,[20, 29] as shown in the increased risk of ACL injury beginning in high school.[4, 12, 13, 30]

IV. Gender Differences During Reactive Tasks

Because the drop jump is a planned task, it is not a direct indication of the forces experienced by the lower extremity during athletic participation. Thus, while it is an important method of assessing ACL injury risk, analyses of other, more sport-specific tasks should also be considered. These tasks entail a reactive element, in which the subject is unaware of the exact motion or direction he/she will be directed to perform.[2, 27, 30-32]

In order to simulate the mechanism of injury for noncontact ACL injury, subjects may perform an unplanned stop-jump task consisting of the following elements: a two-legged broad jump onto two force plates (one foot on each), immediately followed by a reactive task, either for maximum vertical height or maximal horizontal distance (left or right).[31] When compared to male subjects, females demonstrated significantly less maximum knee flexion, greater maximum knee valgus angle, and greater shear ground-reaction force. The characteristics of decreased knee flexion angle and increased knee valgus angle when landing are especially hazardous to the ACL.[6, 9, 18, 31] The gender disparity during theses tasks provides evidence for the inclusion of reactive tasks within ACL injury prevention programs.[31]

One study[30] of unanticipated cutting maneuvers of high school boys and girls found no difference in knee flexion angle between genders when performing an unplanned task. Valgus knee angles were still found to be greater in females during these activities.

When considering mechanisms of ACL injury, female basketball and soccer athletes are often grouped together.[2, 21, 33] However, it is important to note the differences between the demands of the two sports, resulting in the most common mechanism of injury for the sport, although athletes injure the ACL in a variety of ways, regardless of the sport.[2] In female soccer players, ACL injury occurs most often through a cutting maneuver. In girl's high school basketball, landing is the mechanism of injury in 60% of players, while only 25% of female soccer players injure their ACL in this way.[33] Noncontact ACL injury in basketball frequently involves either landing or cutting/twisting;[1,2] in soccer, the injury most often results from cutting and twisting.[2]

A comparative study was conducted in which female basketball and soccer players performed a combined task of a drop vertical jump and a cutting task.[2] Immediately after landing from the drop jump, subjects were instructed to jump forward, land on both feet, and perform a side-step cut at an approximately 45° angle. The direction of the cut was determined according to the direction of an arrow displayed on a computer screen.

During the drop jump, basketball players landed with greater ground reaction forces and lower stance time than soccer players. During cutting, soccer players had increased ground reaction forces and decreased stance time than basketball players. Because the demands of the two sports are different, common mechanisms of injury are different in each sport. Increased ground reaction forces and decreased stance time reflect an athlete's familiarity with a movement; therefore she is able to perform the movement more quickly. However, this may increase the risk of injury as the knee experiences higher forces over a shorter period of time.[9] Additionally, it has been found that most noncontact ACL injuries occur at high velocity.[2, 9] The findings of this study provide support for sport-specific neuromuscular training, in which athletes focus on proper biomechanics during tasks that they frequently perform during their sport. Basketball athletes should focus on jumping, landing, and cutting, while soccer athletes should focus mainly on cutting maneuvers.[21]

V. Evaluation and Risk Prediction Using LESS

As stated previously, many studies have utilized videographic analyses to determine landing strategies in both males and females.[1, 13, 18, 20, 21] The Landing Error Scoring System (LESS) is a tool that can be used to identify biomechanical movement patterns and errors in technique during a jump landing task.[22] (See Appendix A). It involves the videotaping of subjects' performance of a drop jump task from either the frontal or sagittal angle. The height of the box and number of jumps performed vary among studies.[1, 13, 16, 18, 20-23] The film is then analyzed at two positions of the subject: the first frame showing initial contact of one or both feet with the ground, and at the frame which shows the point of maximal knee flexion. The LESS involves a series of thirteen prompts which can be answered "yes" or "no," with a point value (+0) or (+1) corresponding to the response. There are also two additional prompts regarding the scorer's overall impression of the jump, which can be answered +0, +1, or +2.

The LESS has strong intra-session reliability, intra-rater reliability, and inter-rater reliability.[22, 23] The same research found that item specific intra-rater reliability was strong for each item (percent agreement range 75-100%) and for total LESS score.[22]

The LESS has also been shown to have a correlation in distinguishing between males and females.[18, 23] LESS scores were significantly higher in females than in males, indicating less efficient landing biomechanics. Characteristics commonly seen in females include reduced knee flexion, increased knee valgus, and tibial internal rotation (as indicated by internal rotation of the toes). Females were more likely to land with less efficient strategy, therefore placing them at an increased risk of noncontact ACL injury.[18] Thus, the LESS is considered a reliable tool for assessing errors in movement patterns during jump-landing tasks.[18, 22, 23]

VI. The Effects of Fatigue on ACL Injury

Healthy athletes achieve functional joint stabilization by processing visual, proprioceptive, and vestibular system information, combined with reflexive and voluntary muscle responses.[34, 35] Proprioceptive sense comes from articular and musculotendinous receptors (Golgi tendon organs and muscle spindles), while vestibular system information is gathered from the vestibules and semicircular canals of the ears. This sensory information is processed by the central nervous system, which produces efferent signals resulting in balance and posture maintenance, joint kinesthesia (the ability to sense joint motion) and joint position sense (the ability to detect joint position), which may affect their ability to stabilize the knee.[34] Females may have a decreased ability to stabilize the knee and as a result, are predisposed to ACL injury.[34] The majority of athletic participation is performed in a state of fatigue; hence it is necessary to consider the effects of fatigue on the risk of injury in general, and specifically in regards to the ACL. This may aid in the determination of causative factors as well as the design of injury prevention programs. A variety of fatiguing protocols have been utilized, but few[44,45] were functional to the sport of basketball.

Muscular fatiguing protocols have been shown to increase knee joint laxity in both male and female athletes, placing the ACL at a higher risk of injury.[34-39] By increasing joint laxity, muscular fatigue indirectly alters proprioception and kinesthetic ability, which may place the fatigued athlete at a higher risk of ACL injury.[40] A fatiguing protocol of the quadriceps and hamstrings on an isokinetic dynamometer resulted in decreased knee joint kinesthesia, and delayed contraction of the medial hamstring muscles and the lateral gastrocnemius muscle, which assist the ACL in preventing anterior tibial translation.[34, 39] A second study[41] which used an isokinetic protocol found an average increase of 32.5% in anterior tibial translation, as well as slowed muscle responses of the hamstrings, quadriceps, and gastrocnemius following fatigue.

Fatigue elicited by a closed chain isokinetic dynamometer, similar to a Stair Master machine, has been shown to decrease subjects' balancing ability.[35] It is suggested that this reduction in balance is related to ligament relaxation resulting in muscle spindle and Golgi tendon organ desensitization. This decrease in afferent signals to the central nervous system would subsequently result in decreased efferent output, eliciting a muscle response that is insufficient to maintain balance.[35] A decrease in proprioceptive and balancing ability is related to an increased incidence of injury.[35]

Other studies[42-45] have used functional fatiguing protocols in an attempt to determine the effect of exercise on the knee joint. A 2-hour cheerleading practice was found to increase anterior knee laxity and hamstring extensibility.[42] Activity has been found to increase knee laxity,[42-45] and increased knee laxity has been associated with an increased risk of ACL injury.[31,41,44] Therefore, exercise may play a role in ACL injury in both males and females.[38, 43-45]

INTRODUCTION

The high rate of anterior cruciate ligament (ACL) injury in women's athletics has been well documented in the past several years.[3, 6, 8, 9] Female athletes are 2-6 times more likely to sustain an ACL rupture than male athletes participating in the same sports.[3, 5, 6, 8-10] The factors that influence this high rate of injury can be grouped into four categories: anatomical, biomechanical, hormonal, and environmental. It is believed that female's increased risk of injury results from a combination of these elements.[17] Anterior cruciate ligament injuries are costly to repair and rehabilitate, placing monetary, physical, and emotional stresses on injured athletes.[3-7] Approximately 70% of ACL injuries are noncontact in nature,[9, 15-17] meaning that the injury occurs in the absence of a direct blow to the knee.[9, 16] The most common mechanism of noncontact ACL injury is a deceleration force in which the knee enters into a valgus position with a small amount of knee flexion combined with tibial external rotation.[1, 4, 5, 13, 24]

Although there is controversy on the influence of fatigue on injury risk, a variety of fatiguing protocols have been shown to increase knee joint laxity in both male and female athletes, potentially placing ligaments such as the ACL at a higher risk of injury.[34-39, 44, 46] It has been documented that female basketball players are one group with a high risk for ACL injury. However, few studies[44, 45] have examined the effects that an actual basketball practice may have on this risk.

Current research regarding the effects of fatigue on biomechanics is inconclusive.[28, 34, 37, 44-47] Further, little is known about the effects of a functional fatiguing intervention, such as practice, on jumping and landing biomechanics. The LESS is a screening tool that uses video feedback to grade landings based on 15 biomechanical factors. A higher LESS score indicates undesirable landing mechanics, as higher scores have been shown to correspond with an increased risk of ACL injury.[19] LESS scores may be used to predict when ACL injury risk is at its highest, whether at the beginning of practice (non-fatigued state) or near the end of practice (fatigued state).[18, 22] The LESS has not been used to evaluate individuals following any form of exercise; however, it may be used for analysis of landing biomechanics following a functional fatiguing protocol. Therefore, the purpose of our study was to examine the effect of a two-hour basketball practice on the LESS scores of female collegiate basketball athletes.

METHODS

I. Study Design

We utilized a 2x2 repeated measures design in our study. The independent variables were time (pre-intervention and post-intervention) and session (experimental and control). The dependent variable was LESS scores for each drop jump. Subjects (n=10) participated in two data collection sessions in the Lynchburg College gymnasium. The order of the sessions was determined randomly, and sessions were separated by approximately three days.

For the purposes of our study, the fatiguing intervention was defined as the typical two-hour basketball practice on 2 separate days; the practices were similar in style and duration. The pre-intervention state was defined as the state of the athlete before practice; the post-intervention state was defined as the athlete's state following the intervention of practice. Experimental measurements consisted of a subject's LESS scores following the intervention of practice. LESS scores were determined for both practice and control states.

Six athletes performed the experimental procedure first, while four performed the control procedure first. The experimental session consisted of a series of five drop landings from a 34 cm plyometric box, basketball practice (approximately two hours in duration), and another series of five drop landings. The control session consisted of five drop landings, a rest period of two hours, followed by another five drop landings. All subjects' drop landings were videotaped for later review with the LESS.

II. Subjects

Ten healthy members of the Lynchburg College Women's Basketball Team (age=18.95±0.31 years, height=171.2±10.52 cm, mass 65.86±11.55 kg) volunteered to participate in the study during the 2006-2007 academic year. The Institutional Review Board of Lynchburg College approved the study. A team meeting was held to allow the researcher to explain the purpose of the study and the responsibilities of the subjects. At this time, informed written consent was obtained and subjects provided demographic and medical history information. Subjects were required to be free of lower extremity injury or surgery for one year and be fully capable of participating in basketball practice at the time of testing. Subjects were also required to be capable of performing a drop jump without pain. No exclusions were necessary based on the established criteria. One subject failed to attend one of the testing sessions, and thus was not included in final data analysis.

Identification numbers were alphabetically assigned to each subject according to last name. These numbers were used for the duration of the study. Additionally, subjects were assigned to either Group A or B by the flip of a coin.

III. Testing Procedures

Subjects were instructed to wear a t-shirt, athletic shorts, and sneakers to the testing sessions and were told to wear the same shoes on both days. They were to avoid as much physical activity as possible prior to their testing session. All data collection was done by the same researcher (CW).

Data collection occurred over a 3 day period; however, a subject was required to be present on only 2 of the days. The order in which she performed the intervention or control was determined by membership in Group A or B. Group A (n=6) received the fatiguing intervention on the first day of testing (February 15, 2007) and the control on the second day of testing (February 18, 2007). Group B (n=4) received the control on the second day of testing (February 18, 2007) and the fatiguing intervention (February 21, 2007). (See Table 1).

Drop jump testing occurred in the Lynchburg College Fitness Center in Turner Gymnasium. A metal plyometric box with a wooden top was set at a height of 34 cm. A rubber mat 2 cm in height was placed on the floor to provide a softer landing surface; this made the total height of the jump 32 cm. Prior to each subject's initial session, the lead researcher explained the drop jump task without providing any verbal instruction or physical demonstration of the proper way to land. The subject first performed a five-minute warm-up period on an upright stationary bicycle. The subject performed three practice drop jumps before videotaping began. The lead researcher then sat in front of the testing area and videotaped the subject from the neck down. A Sony camcorder (Sony Corporation, New York, NY) was used in taping. Each subject was videotaped performing five drop jumps with no rest time between tasks. She then performed the intervention (practice) or control (rest), according to her designated protocol for that day. Subjects were expected to participate fully in all parts of practice, which took place in Lynchburg College's Turner Gymnasium.

Following the 2-hour time period, the group being retested returned to the testing area where they performed the same sequence of warm-up and drop jumps a second time.

IV. Data Analysis

Once videographic data was collected, each jump was scored by the lead researcher using the Premier Pro 1.5 software (Adobe Systems Incorporated, San Jose, CA) and a LESS scoring sheet. The researcher was blinded to the group being assessed while scoring the landings to decrease biasing. A total of 4 sheets were completed for each subject: pre- and post-intervention and pre- and post-control.

V. Statistical Analysis

Data was statistically analyzed using two separate 1x2 ANOVAs, 1 for the experimental session and 1 for the control session. This was performed in order to determine whether the treatment intervention of fatigue had a significant effect on subjects' LESS scores (the dependent variable). Results were analyzed using SPSS (SPSS Inc, Chicago, IL). The *a priori* alpha level was set at $P \leq .05$.

RESULTS

LESS scores for the experimental session increased from the pre-intervention score (6.09±1.89) to post-intervention score (6.89±2.23). (See Figure 1). The control session yielded no difference from pre-control score (6.20±1.36) to post-control score (6.42±1.32). (See Figure 2). LESS scores significantly increased following the experimental session ($F_{1,8}$=7.20, p=0.03, n^2=0.47, 1-β=0.65). No significant difference was found between pre ($F_{1,8}$=1.56, p=0.25, n^2=0.16, 1-β=0.65) during the control session.

DISCUSSION

Our results support the hypothesis that a two-hour basketball practice increases subjects' LESS scores. Although recent research has identified many factors that may contribute to the increased risk of ACL injury in females, the majority of these are not well understood. These factors can be grouped into four categories: anatomical, biomechanical, hormonal, and environmental, and it is believed that female's increased risk of injury results from a combination of these elements.[17] Little is known about the effect of exercise on these factors, as research in this area is inconclusive. The objective of our study was to examine the effect of a 2-hour basketball practice on the LESS scores of female collegiate basketball players. Increased LESS scores correlate with an increased risk of knee injury.[19] Our study found that the intervention of exercise increased subjects' LESS scores, indicating the presence of less efficient biomechanics in a post-intervention state. We believe that this is due to the induction of both central and peripheral fatigue, both of which may have detrimental effects on the body's ability to protect itself from injury.[38, 43-45] However, we make these conclusions in light of the fact that some, or potentially all, subjects may not have been fully fatigued.

The LESS has not previously been used to evaluate subjects in a state of fatigue. However, in response to various fatiguing protocols, subjects have been shown to exhibit increased anterior knee laxity,[34, 41, 42, 44, 45] decreased balance/proprioceptive abilities,[34, 42, 46] altered neuromuscular characteristics,[1, 16, 20, 25, 26, 28] and altered muscle recruitment patterns.[20, 26, 28, 31, 34, 41] These traits are thought to increase the likelihood of knee injury.

We chose to use the LESS because of its strong intra-session, intra-rater, and inter-rater reliability.[22, 23] The LESS is a practical tool that is simple to use. The LESS has only been used to evaluate subjects in a non-fatigued state; we assumed that this degree of reliability would also be present when we used the LESS to score subjects following a fatiguing intervention.

Muscular fatigue has been traditionally characterized "not only by a loss of force-production capability but also by localized discomfort and pain.[34]" We defined fatigue as the post-intervention state of the subjects following a 2-hour basketball practice, as contrasted with the post-control state of subjects following the 2-hour rest session. Previous researchers have induced fatigue in subjects in a variety of ways that can be grouped into functional and simulated fatiguing protocols. In a functional protocol,[42-45] subjects actually perform sport activities. In a simulated protocol,[28, 34, 41] subjects perform knee flexion and extension exercises on an isokinetic dynamometer until an established number of repetitions or predetermined decrease in force production is reached. There are benefits and drawbacks associated with the use of both types of protocols, and these should be kept in mind when considering the results of such studies.

Additional researchers have utilized functional sport participation as a fatiguing protocol. "Game-style" basketball participation performed by semiprofessional female basketball players resulted in increased anterior, posterior, and total anterior-posterior knee laxity following activity.[44] A 90-minute basketball practice and a 10-km race both resulted in increased knee laxity in female subjects that remained elevated for 90 minutes following activity.[45] In response to running 5.6 km (3.5 miles), torsional knee laxity increased and remained elevated for 52 minutes following the run.[43] A 2-hour cheerleading practice has been shown to increase anterior knee laxity and hamstring extensibility and decrease dynamic postural stability in both male and female cheerleaders.[42] Joint laxity has been associated with an increased risk of ACL injury,[34, 41, 44] cited as 2.7 times greater in a prospective study of cadets at theUnited States Military Academy.[14]

The exercise protocols of these studies are similar to the joint forces occurring during sport participation.[42-45] However, it is important to note that the use of a functional fatiguing protocol alone may not allow a way of ensuring that fatigue is actually reached by subjects. Because responses to exercise are individualized, a true state of fatigue may be reached by some subjects and not others. This was most likely the case in our study. We assumed that following 2 hours of practice, subjects would be fatigued; however, there was no way to measure this for certain. Therefore, we use the word "fatigued" with caution; the phrases "post-intervention" or "following fatigue" are more appropriate.

The key benefit of fatiguing protocols performed on isokinetic dynamometers is that they produce easily quantifiable results. Although such protocols subject the knee to repetitive stress and achieve muscular fatigue, they do not effectively simulate the forces associated with sport participation.[47] This is because the joint forces which result from exercise on the dynamometer are more similar to those experienced during activities of daily living (such as ascending or descending stairs) rather than those experienced during sport.[45, 47] The shearing forces associated with athletic movements such as cutting and pivoting are not able to be replicated by exercise on an isokinetic dynamometer.[45,47]

Several studies[28, 34] have found evidence to the contrary. One study[34] found decreases in kinesthetic ability and altered muscular activity in both male and female subjects following fatigue on an isokinetic dynamometer. An increase in knee laxity was not found for either gender. Another study[28] noted that female collegiate athletes landed from jumps of 25 and 51 cm with greater knee flexion angles than males. This mechanical characteristic has previously been considered a desirable quality of landing; therefore, male athletes have traditionally been found to posses greater knee flexion angles than female athletes.[6, 9, 15, 18] Squat power lifts failed to increase laxity in female athletes, possibly because they place compressive forces on the lower extremity, as opposed to the shearing forces involved in sport motions.[45] Other factors relating to the disproportionate incidence of ACL injury among female athletes must still be examined. This demonstrates the necessity for the continuation of research in this area.

We believe that the post-intervention increase in LESS scores may be due to the onset of central and peripheral fatigue, as well as the possible interaction of the athlete's mental state following activity. These two aspects may have detrimental effects on the body's ability to protect itself from injury.[38, 43-45]

The central nervous system (CNS) consists of the brain and spinal cord. The spinal cord sends afferent (sensory) input to the brain, where signals are processed. The brain then sends an efferent (motor or somatic) response in order to elicit a change at some location in the body. Central fatigue refers to the fatigue of the CNS in response to a stimulus, such as exercise. Exercise may decrease the number and rate of motor unit activation by the CNS.[48] It may also involve a slowed frequency of action potentials to activate these muscles. This combination may slow muscular responses (efferent signals), leading to decreased ability of the muscles to provide dynamic stability to a joint. This may explain why our subjects exhibited less efficient biomechanics following the intervention of practice. If knee musculature is unable to provide dynamic stability, the movements of the joint are less protected.[48] The joint may experience harmful positions, such as increased knee valgus angles, decreased knee flexion angles, and tibial rotation, all of which place the ACL at an increased risk of injury.[1, 4, 5, 13, 24] Thus, central fatigue may play a role in the increase in LESS scores following a 2-hour basketball practice.

Peripheral fatigue involves the detection of afferent and efferent signals by mechanoreceptors, which are located throughout joints, ligaments, and muscles. Mechanoreceptors are structures that detect changes in muscle tension (Golgi tendon organs) and muscle length (muscle spindles) and send signals to the CNS.[49] In response to fatigue, mechanoreceptors increase in length, become less receptive to muscle tension and length, and therefore send weakened and/or delayed afferent signals to the CNS. Altered signals will lead to a less efficient muscular response, ultimately resulting in a decreased ability to stabilize the joint.[42] This in turn may decrease a joint's control of precise movements and delay muscle activation.[41, 48] Peripheral fatigue may explain subjects' poorer biomechanics following basketball practice because their muscles were not able to react in time to prevent joints from entering dangerous positions, such as valgus positioning of the knee joints.

Specifically to the knee, mechanoreceptors of the ACL and surrounding joint structures influence the activity of thigh musculature in order to achieve dynamic stabilization.[42] When mechanoreceptors lengthen due to fatigue, signals are altered and the muscle response is inefficient, possibly leading to a decreased ability to stabilize the knee joint.[41, 42]

There is the possibility of other factors that may have caused subjects to land differently following practice. Subjects may have been mentally, as well as physically, fatigued following practice. Their concentration may decreased following practice as compared to pre-practice when their minds could be considered "fresh." Mental fatigue is highly personal, and may be worsened by a variety of psychological factors, such as the perception of a poor performance, a conflict with a coach or teammate during practice, and/or the desire to finish practice. These psychological factors may also contribute to injury.

The relationship between fatigue and knee injury is presently unknown. Muscle fatigue appears to affect the dynamic stability of the knee and alter neuromuscular responses.[38, 43-45] In other words, the body is less able to protect a fatigued knee from injury. Research in this area should continue in order to determine the causes of such altered characteristics. Future research should focus on standardizing a way to quantify fatigue, particularly on a sport-specific basis. For example, an isokinetic dynamometer could be used to measure force output prior to a functional fatiguing protocol, which would be performed until the desired fatigue level was reached (as measured on the dynamometer). This would provide a quantifiable measure of fatigue as well as a fatiguing protocol incorporating the demands of sport participation. A rating of perceived exertion (RPE) chart could be used; this chart is numbered from 1-10 with corresponding descriptions of the individual's state, and subjects indicate their fatigue by selecting a number. A VO_2 max test could also be used to quantify an individual's percent of fatigue.

A major limitation of our study was the fact that we did not establish a set fatiguing protocol for each day of testing; we assumed that a 2-hour practice would fatigue subjects enough to result in changes. Further, in considering our results, it must be noted that the time it took to walk from the gymnasium to the fitness center may have provided a recovery time for subjects. Their post-practice LESS scores may have been different had this recovery time been eliminated. The intensity of practices most likely varied from day to day, and may not simulate the demands of a game. Future research could examine LESS scores before and after a game, taking into consideration the different amount of playing time of each subject. However, the intensity of a game is generally thought to be higher than that of practice; if our results were applied to a game situation, LESS scores would be expected to increase.

Also, the fitness level of each subject, while expected to be relatively high because testing occurred midseason, is individualized to each subject. Three subjects stated that they had previously received jump landing instruction between the ages of 12 and 18. Two subjects attended both performance enhancement centers and landing instruction sessions. Our study did not address the influence of these factors on LESS scores, but training programs focusing on the development and improvement of neuromuscular control of the lower extremity have been shown to greatly reduce the incidence of ACL injury in female athletes.[2, 50-53] Future research could examine the effects of fatigue on the LESS scores of trained and untrained individuals, and before and after jump training.

Still, through screening measures such as the LESS, researchers have been able to identify individuals at a high risk of injury and intervene to decrease this risk. Training programs involving the 3 components of plyometric training, strength training, and sport-specific training have been shown to be effective in reducing the risk of ACL injury in female athletes.[2, 50-53] The combination protocol is believed to be more effective than any one type of training alone. High-intensity plyometric training may be the most effective form of training, as it most closely simulates sport participation.[52, 53] It results in adaptation of the body's muscles, connective tissue, and nervous system to perform sport motions more efficiently. This type of training focuses on proper technique and body mechanics, which have been shown to reduce the risk of ACL injuries.[50, 51, 54]

High school-aged female basketball, volleyball, and soccer players participated in a six-week training intervention that consisted of stretching, plyometrics, and weight training.[2] The rate of noncontact ACL injuries was reduced by 72% in the trained athletes as compared to the control athletes. A program performed by Norwegian handball players that incorporated these elements decreased ACL injury risk by 36%.[51] Female soccer players participated in a similar training program over the course of two years. Trained subjects experienced an 88% decrease in ACL injuries in the first year, and a 74% decrease in the second year. Over the 2 years, this was equivalent to a total of 67 ACL ruptures occurring in the untrained group, with only 6 occurring in the group that had participated in training.[50]

Interventions must also take into consideration the deleterious effects of fatigue on the body, and its potential implications on increased injury risk. In our study, LESS scores increased in response to the intervention. In order to decrease ACL injury rates, coaches and certified athletic trainers may need to design preventative programs to incorporate additional conditioning activities. The better conditioned an athlete is, the longer she will be able to perform without fatigue. This could be implemented by having athletes participate in the day's practice until they become fatigued, and then begin conditioning activities with a lower likelihood of ACL injury. Through training, the athletes would be able to practice for a longer duration before the onset of fatigue. A second option would be to allow tired players to rest during games, effectively removing the likelihood of injury during the time they are out of competition. Without the detrimental effects of fatigue on the body, the lower extremities may be better protected from injury. If athletes are taught the most efficient way to land to reduce injury, they must also be monitored to ensure that they follow instructions. This is especially important when the athlete is in a state of fatigue. This is one factor related to ACL injury risk that may be modifiable.

Research in the area of prevention is crucial to reducing the risk of ACL injury in female athletes, especially those participating in cutting and landing sports such as basketball and soccer. Future research should continue in the attempt to identify causative factors for this phenomenon, as well as the impact of fatigue and athletic participation on these factors. This may provide additional evidence in favor of preseason conditioning programs and jump landing training programs.

CONCLUSIONS

Our study evaluated the effects of a 2-hour basketball practice on LESS scores of female basketball players. LESS scores increased in response to the intervention of the 2-hour practice. LESS scores have been shown to be a valid predictor of ACL injury risk, subjects' increased LESS scores in the post-intervention state may indicate an increased risk of ACL injury in this state. Additional research is warranted to determine causative factors for these potential changes and the increased risk of ACL injury that may result. Also, further research should investigate the effect of fatigue on female athletes. This information may aid in the design of prevention and conditioning programs for female athletes to potentially decrease their risk of ACL injury.

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Appendix A. LESS Scoring Sheet

Landing Error Scoring System (LESS) **Date:** ___________

Subject ID:_________ **Rater:**_______________________________ **Project:** _________

* Note: Initial contact is ***first frame*** that shows ***any*** foot contact with the floor
* Note: if asymmetrical landing, score the instrumented leg or the first landing leg

1. Ankle Plantar-Flexion Angle at Initial Contact: Toe to Heel **Trial #1 #2 #3 #4 #5 #6**

___|___|___|___|___|___

(+0) Yes
(+1) No

2. Knee Flexion Angle at Initial Contact: Greater than 30° **Trial #1 #2 #3 #4 #5 #6**

___|___|___|___|___|___

(+0) Yes
(+1) No

3. Trunk Flexion Angle at Initial Contact: Trunk in front of hips **Trial #1 #2 #3 #4 #5 #6**
#5 #6

___|___|___|___|___|___

(+0) Yes
(+1) No

6. Initial Foot Contact
Trial #1 #2 #3 #4 #5 #6

___|___|___|___|___|___

(+0) Symmetric foot contact
(+1) Asymmetric foot contact

7. Foot Position at Initial Contact: Toes > 30 of ER
Trial #1 #2 #3 #4 #5 #6

___|___|___|___|___|___

(+1) Yes
(+0) No

8. Foot Position at Initial Contact: Toes > 30 of IR
Trial #1 #2 #3 #4 #5 #6

___|___|___|___|___|___

(+1) Yes
(+0) No

(+1) Lateral deviation of sternum over hips

13. Knee Valgus ROM: Greater than great toe
Trial #1 #2 #3 #4 #5 #6

___|___|___|___|___|___

(+1) Yes
(+0) No

14. Joint Displacement: (Sagittal Plane)
Trial #1 #2 #3 #4 #5 #6

___|___|___|___|___|___

(+0) Large joint motion (quiet / soft)
(+1) Average joint motion

___|___|___|___|___|___

(+0) Yes
(+1) No

4. Knee Flexion ROM GREATER than 30°
Trial #1 #2 #3 #4 #5 #6

___|___|___|___|___|___

(+0) Yes
(+1) No

5. Trunk Flexion at Max Knee Flexion Angle: Trunk in front of hips **Trial #1 #2 #3 #4**

9. Stance Width at Initial Contact: LESS than shoulder width **Trial #1 #2 #3 #4 #5 #6**

___|___|___|___|___|___

(+1) Yes
(+0) No

10. Stance Width at Initial Contact: GREATER than shoulder width **Trial #1 #2 #3 #4 #5 #6**

___|___|___|___|___|___

(+1) Yes
(+0) No

11. Knee Valgus Angle at Initial Contact: Knees over mid-foot **Trial #1 #2 #3 #4 #5 #6**

___|___|___|___|___|___

(+0) Yes
(+1) No

12. Lateral Trunk Flexion at Initial Contact
Trial #1 #2 #3 #4 #5 #6

___|___|___|___|___|___

(+0) Sternum centered over hips
(+2) Small joint motion (loud / stiff)

15. Overall Impression
Trial #1 #2 #3 #4 #5 #6

___|___|___|___|___|___

(+0) Excellent (maintains frontal alignment, lands w/ > 30° of knee flexion, undergoes > 30° of displacement)
(+1) Average (small frontal motion, straight/stiff landing)
(+2) Poor (large frontal motion)

Total Score #1___ #2___ #3___ #4___ #5___ #6___

Table 1. Randomization of Study Design

Group	Day 1	Day 4	Day 7
A (n=6)	Intervention	Control	
B (n=4)		Control	Intervention

Figure 1. Average LESS Scores: Intervention Session

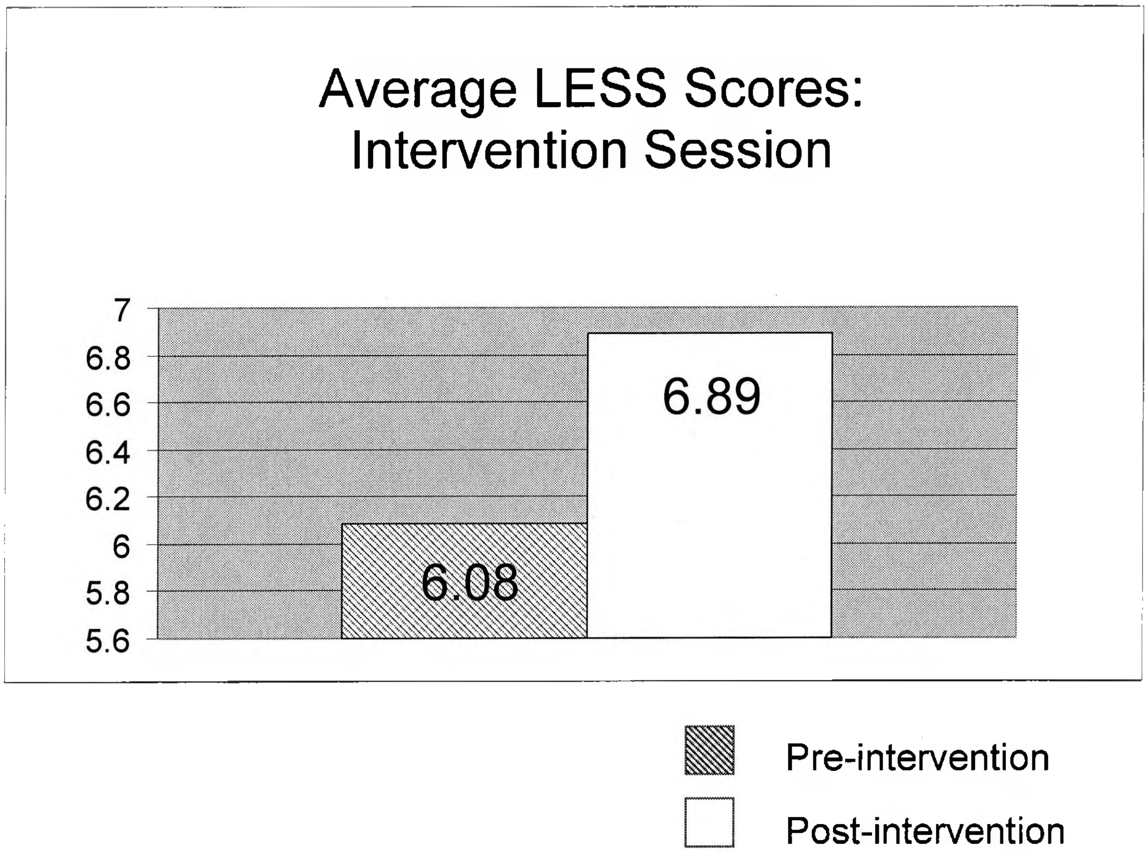
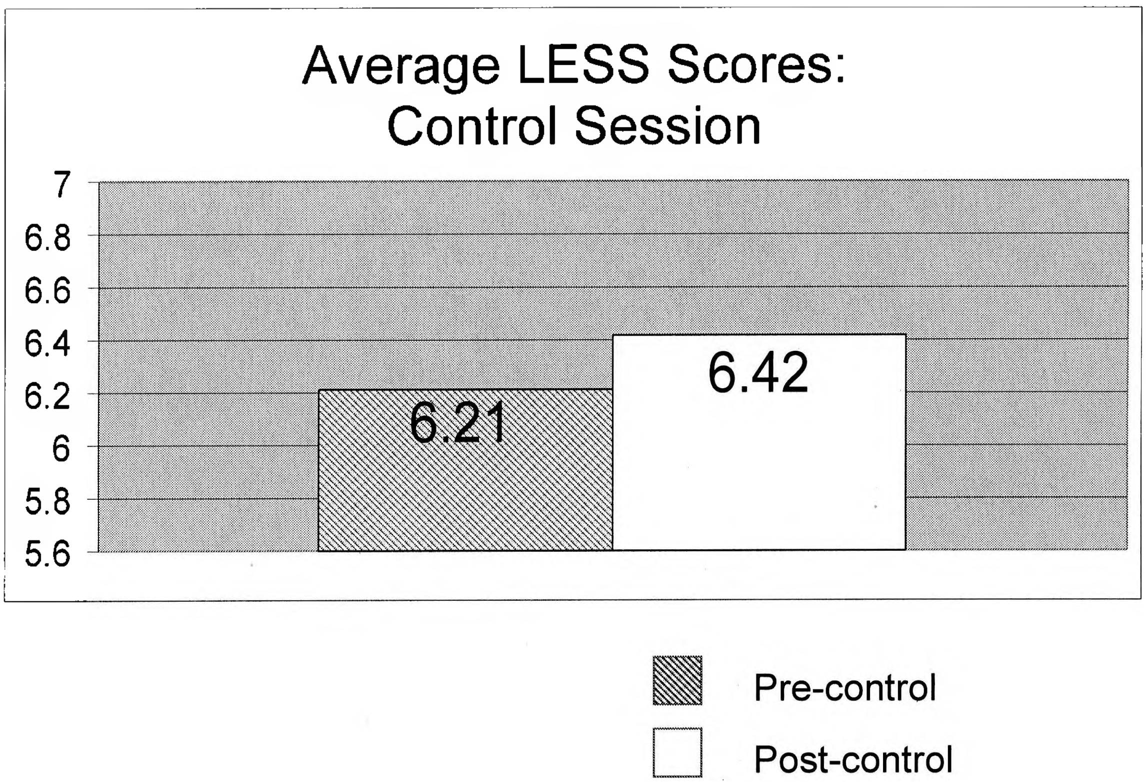


Figure 2. Average LESS Scores: Control Session



GLOSSARY OF TERMS

Anterior cruciate ligament (ACL) – a knee ligament with insertions on the femur (the thighbone) and the tibia (the shinbone); its function is to prevent anterior translation of the tibia and rotation and hyperextension of the knee

Drop vertical jump – a task in which an individual stands on top of a plyometric box, drops down directly off the box, and immediately after landing, performs a maximum vertical jump with both arms in the air

National Collegiate Athletic Association (NCAA) Injury Surveillance System – a database of injury information collected from a representative sample of NCAA Division I, II, and III institutions located throughout the United States

Valgus – a joint moving toward the midline of the body; may be the result of an individual's anatomical structure, a lateral force enacted on the joint, or a biomechanical insufficiency

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