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A Feedback Inclusive Neuromuscular Training Program Alters Frontal Plane Kinematics

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INTRODUCTION

Anterior cruciate ligament (ACL) ruptures occur at an estimated range of between 80,000 and 250,000 each year (9, 38) with the general population incurring injuries at an approximate rate of 1 in 3000. Multiple studies have reinforced the fact that female athletes are at a greater disposition than their male counterparts to suffer a non-contact ACL injury (1, 13). Overall, studies have shown that the female athlete is more likely to suffer an ACL injury 2-8 times greater than that of the male athlete (13, 27) with surgery rates being twice that of males (6). Some studies have directly looked at the impact of ACL injuries in collegiate athletes, exposing an approximate rate of more than 2,000 ACL injuries per year (1, 16). Within this unique population of young athletes, collegiate female soccer players have become the focus of many ACL injury prevention programs (3, 8).

Over the past decade, ACL injury prevention related programs focusing on the strength and conditioning of the athlete have been developed and researched, showing promising results in decreasing injury rates (8, 13, 23). Specific research studies that have demonstrated positive effects in reducing the occurrence of ACL injuries are all-inclusive in design, including varying combinations of strength, balance, proprioception, feedback or plyometric training, in order to manipulate neuromuscular variables to reduce the risk of incurring an ACL injury (3, 8, 11-13, 23, 29, 31). The positive effects of reducing ACL injury risk seen within the noted studies is thought to occur from a multifaceted alteration in biomechanical factors; including strength, balance, spatial awareness, stability, and coordination. Though this may be a common belief (28, 33), the influence of change of each factor remains unknown, as well as the synergistic effect one factor may have upon another. Despite the influx of the ACL prevention programs over the past decade, the incidence of ACL injuries amongst the college athlete population continues to increase (16), with aspects such as dose-response, optimal timing with respect to the sport season, and lack of compliance being

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proposed as possible contributing factors to this continued increase (37). Whatever the limiting factor may be, participating in an ACL prevention program has demonstrated a relative risk reduction of 70% in regards to a non-contact ACL injury (10), demonstrating the necessity of their implementation.

Of the previous ACL intervention studies, few studies (5, 11, 12, 22, 29, 30) have directly examined the role of resistance training in relation to biomechanical adaptations that influence the risk of an ACL injury. Those studies have returned mixed results on the effects of the resistance training protocols to positively adapt biomechanical risk factors. To assist with the effectiveness of a resistance training protocol, instruction is vitally important in performing technical movements correctly. Instruction, in the form of augmented feedback, has also been utilized by few studies that focus on ACL injury prevention aspects (11, 25, 26, 29, 31). The use of augmented feedback in relation to ACL injury prevention has focused on bringing about biomechanical changes in landing patterns. Techniques such as viewing expert and self video with key instructional cues (11, 31), auditory self-cued feedback (25), and verbal instruction post-performance (26), have demonstrated positive effects in altering landing patterns. The majority of these studies examined the use of augmented feedback within single session trials, demonstrating only the immediate effects of the feedback. Oñate et al (31) performed a retention test one week after providing augmented feedback, and found that the biomechanical changes influenced by the feedback were still retained. The addition of augmented feedback is vital to all aspects of an all-inclusive injury prevention program, in that a participant must have knowledge of their performance in order to make adaptations. There is a lack of knowledge within the concept of utilizing resistance training and augmented feedback as viable components of an all-inclusive ACL injury prevention program designed to bring about biomechanical adaptations.

The purpose of this study is to compare the effects of a 10-week feedback inclusive neuromuscular intervention on isometric strength and jump-landing mechanics at the hip and knee during a stop-jump task. It was hypothesized that the 10-week feedback inclusive neuromuscular intervention would decrease hip and knee moments, increase hip and knee flexion angles, decrease knee abduction angles, and increase hip abduction angles at initial contact, peak knee flexion and peak stance. It was also hypothesized that isometric strength measurements would increase after participation in the neuromuscular intervention.

METHODS

A non-randomized observational experiment was conducted in order to assess the effects of a neuromuscular training intervention. The study took place during the collegiate soccer off-season (January – April). Three separate resistance-training groups, with comparable resistance volume, were devised based on the head soccer coach’s desired morphological outcomes. Participants were placed into their respective resistance-training group, strength (n = 4, STR), maintenance (n = 5, MNT), or endurance (n = 3, END), prior to pretesting. All three groups performed their respective workouts at the same time and day. All three groups performed the same field conditioning sessions as a single group. Participants were pre-tested one week prior to the initial session, and post-tested within one week of concluding the final session of the 10-week training intervention. All resistance training sessions and field conditioning sessions were conducted by a National Strength and Conditioning Association certified strength and conditioning specialist (CSCS). The Old Dominion University Institutional Review Board approved this study.

Subjects

Twelve female soccer athletes (19.2±0.8 years, 1.67±0.1m, 60.2±6.5Kg) from an NCAA Division I University participated in this study. Demographics for the participants according to their assigned groups are presented in Table 1. A significant difference ($p = 0.007$) existed between groups with respect to body mass prior to training. Pre-training, the STR group (56.45 ± 1.97 kg) was significantly lighter than both the MNT group (64.60 ± 3.65 kg, $p = 0.009$) and the END group (63.63 ± 2.83 kg, $p = 0.036$). Post-training, there was no significant difference between the groups for body mass. The participants had 14.17 ± 1.75 years of experience playing soccer, with at least a one season of playing experience at the collegiate level. Inclusion for the study required the participants to be free from any lower extremity injury within the six months preceding the start of the initial testing session, as well as team physician clearance to practice and play. Prior to the start of each testing session, each participant read and signed the informed consent form that was approved by the University's Institutional Review Board.

The study had fifteen participants initially, with three participants voluntarily removing themselves from the study. All twelve participants in the study completed a minimum of 95% (19 of 20) of the resistance-training sessions, and 95% (19 of 20) of the field conditioning sessions.

Laboratory Testing

Participants reported to the Motion Analysis Laboratory, signed the informed consent if they agreed to participate, and completed a demographic assessment. Leg length measurements were taken bilaterally from a supine position for an overall leg length and shank length. Overall leg length was measured from the greater trochanter to the lateral calcaneous, and shank length was measured from the lateral joint line of the knee to the lateral calcaneous.

Bilateral isometric strength measurements for the hip and knee were then obtained from the participant utilizing a portable fixed dynamometer (BTE Evaluator, BTE Technologies, Inc., Hanover, MD). To obtain reliable results, testing protocol and the positioning of the participant in relation to the portable fixed dynamometer followed the procedures outlined by Kollock et al (20). The dynamometer was secured to the wall on one end and attached to the participant utilizing a nylon ankle strap, placed superior to the medial malleolus. For each measurement, the participants were positioned such that the dynamometer was parallel to the direction of the isometric contraction. Isometric hip strength measurements for flexion, extension, adduction, and abduction were assessed in a standing position. In the standing position, participants were instructed to maintain an upright posture and a straight leg in order to isolate the musculature about the hip. In a seated position, isometric strength measurements were obtained for hip internal and external rotation, as well as knee flexion and extension. The participants were fitted to the chair so that their torso was flexed 90° from their thigh, as well as the shank being flexed 90° to the thigh. For the seated position, participants were secured to the chair with straps across their thighs and torso, and were instructed to place their arms across their chest so that external leverage could not be utilized. Testing protocol required the participant to perform three maximal isometric contractions for each strength measurement. Each maximal contraction was to be maintained for 5 seconds, separated by a 10 second rest interval. Peak force was recorded for each trial and all three trials were required to fall within a 10% coefficient of variance of one another to qualify as a reliable measurement. Individual isometric strength was normalized through multiplying by the participants respective lever arm (overall leg length for standing measurements, shank length for seated measurements) and dividing by the participants body mass [force (N) × lever arm (m) / body mass (kg)] (36).

At the completion of the isometric strength testing, participants then performed a soccer-specific dynamic running motion that consisted of an unanticipated stop-jump task. Two Bertec force plates (Model 1060-NC, Bertec Corporation, Columbus, OH) were utilized to capture kinetic data at 1080Hz. To capture marker trajectory data, an 8-camera Vicon MX system (Vicon Motion Systems, Los Angeles, CA), set to a rate of 270Hz, was utilized. Forty retro-reflective markers, thirty tracking and ten calibration, were placed bilaterally on the participants' lower extremities to include the posterior superior iliac spine, iliac crest, greater trochanter, thigh, medial joint line of the knee, lateral joint line of the knee, shank, medial malleolus, lateral calcaneous, heel, head of the first metatarsal, head of the fifth metatarsal, intermediate cuneiform, and the peroneal trochlea of the calcaneus. For the thigh and shank, clusters of four markers, attached to rigid backing plates, were utilized. Two calibration captures were taken prior to the initiation of testing. The first calibration capture was a dynamic "hula motion" performed for three consecutive circles. This capture was taken in order to calculate hip joint centers (34). The second calibration capture taken was a static capture utilized to reconstruct the participant. After the calibration captures were completed, the calibration markers were removed.

The participant then performed dynamic running tasks that required the successful completion of 5 unanticipated stop-jump tasks, as well as 5 unanticipated side-step cutting tasks. The unanticipated tasks were controlled through a custom designed computer program that randomized the trials, and provided a visual cue projected on the wall in front of the participant. An infrared beam, set 2 m prior to the front edge of the force plates, sent a signal, when physically occluded, to the computer running the randomization program to randomly display either a side-step cutting task or stop-jump task. The participant had an approach distance of 6 m and had to obtain a velocity of at least 3.3 m/s prior to making contact with the force plate. The participants velocity was measured by two sets of digital timing gates (Speed Trap II, Brower Timing Systems, Draper, UT), set 2 m prior to the front edge of the force plates and inline with the front edge of the force plates. To complete a successful trial of the side-step cutting task, the participant made contact with their dominant foot within the area of a single force plate and performed a 45° cut to their non-dominant side (24). A successful trial of the stop-jump task required the participant to make simultaneous contact with both feet within the area of each individual force plate and immediately perform a maximal vertical jump; the participant was not required to land back on the force plates (4). After the successful completion of the dynamic running tasks, the testing session was complete. As the sidestep cutting task did not fall within the scope of this study, it was only used for randomization of the unanticipated tasks and was not further analyzed within this study.

Training Intervention

Resistance-training—The resistance-training program used in this study was designed to mimic an off-season program within the collegiate setting. The focus of the resistance-training program progressed from attaining proper form while performing the lifts under light loads to maintaining proper form while increasing the intensity of the loads. The resistance-training portion of the intervention occurred in the early evening on Monday and Wednesday of each week in the university's varsity weight room. Each training session lasted for approximately 60 minutes. A team warm-up was completed prior to each training session and consisted of a 3-minute jog and individual stretching session. Each group performed the same resistance training exercises, with varied volume and intensity between the groups. It is important to note that all groups maintained the same volume and intensity for the modified Olympic lifts (dumbbell single arm power clean, barbell power jerk, barbell hang clean, and dumbbell single arm jerk). The amount of weight utilized for each exercise was self-selected by each individual participant. A two-week cycle was used to alternate the resistance exercises to add variety to the ten-week intervention. The STR group utilized a low volume of exercises with a self-selected rest interval, whereas the END group was assigned a high volume of exercises and was restricted to a 30-second rest interval between each exercise. Table 2 depicts the resistance training exercises utilized over the ten-week intervention and the varying volume between the STR and END groups. The MNT group utilized a hybrid scheme between the STR and END groups, performing a STR protocol one day and an END protocol on the other day, with the order altered each week, repeating the pattern of STR-END-END-STR every two weeks.

At the initial resistance training session, the CSCS performed visual demonstrations of each resistance exercise and verbalized cues for performing the exercises. During all testing sessions, the CSCS provided augmented feedback to the participants in relation to their movement patterns and body positioning, both verbally and visually.

Field-conditioning—The design of the field conditioning drills was developed from previous injury programs incorporating plyometrics (13, 23), as well sport-specific drills emphasizing running, cutting, and decelerating (Table 3). The field-conditioning portion of the intervention occurred in the late afternoon on Tuesday and Thursday of each week on the university’s varsity soccer practice field. All participants participated in the same drills with no discrepancy between groups. For the first four weeks the training sessions lasted for approximately 60 minutes, and for the final six weeks the training sessions lasted for approximately 30 minutes. The change in session duration coincided with the onset of the teams’ spring playing season. All field conditioning sessions began with a dynamic warm-up consisting of running form drills and range-of-motion exercises. The focus of the field conditioning drills varied between days, with speed and quickness drills being the focus on Tuesday, and plyometric and agility drills being the focus on Thursday.

The main focus of the field conditioning drills was maintaining proper body positioning and producing proper coordination patterns. All drills emphasized maximum effort and power while maintaining proper body angles during acceleration and jumping, along with body positioning and force attenuation during deceleration and landing. Prior to each drill, the CSCS performed visual demonstrations of each resistance exercise and verbalized cues for performing the drills properly. During all of the drills, the CSCS provided constant augmented feedback in relation to the individual and team performances.

Data Analysis

Visual 3-D (C-Motion Inc., Rockville MD, USA) was utilized to process kinematic and kinetic data. The data was then imported to a custom made Matlab (The MathWorks, Inc, Natick MA, USA) software program to reduce the data into specified time components of initial contact (IC), peak knee flexion (PKF), and peak stance. The data was then output into a Microsoft Excel spreadsheet, where each of the five trials for the stop-jump task were averaged. Joint angles were measured in degrees, whereas joint moments were normalized to body mass (Nm/Kg). Normalized strength and motion data for the stop-jump task were imported to PASW for Mac (version 18.0, SPSS Inc., Chicago, IL) for statistical analyses.

Due to the low number of participants within each group, the effect of the separate resistance training groups was not analyzed as part of this study. As all participants performed the same tasks and volume of resistance training, participants were analyzed as a whole in relation to isometric strength and kinematic and kinetic variables. To assess the effect of training on isometric strength, separate repeated measures ANOVAs were utilized for each dependent variable. Repeated measures ANOVA’s were also used to assess the effect of training on each of the hip and knee dependent variables for the stop-jump task. All dependent variables analyzed through repeated measures ANOVA's met the assumption of sphericity. An *a priori* level of statistical significance was set at $p < 0.05$.

RESULTS

Isometric Strength

The participants in this study demonstrated increases in isometric strength from pre- to post-training (Figures 1 and 2). The training program produced strength increases in all measurements for the participant's left side. Left hip extension was significantly increased ($p = 0.008$, $d = 0.63$) by 26%, causing the left hip extensors to display greater isometric strength than the right hip extensors post-training. Antagonistically, the left hip flexors also demonstrated a significant increase ($p = 0.001$, $d = 0.68$) of 20%. Right hip flexion displayed a similar significant increase ($p = 0.023$, $d = 0.62$) of 18%, but right hip extension produced a minimal increase of 1% post-training. As an imbalance, favoring the right side, within the hip extensors existed pre-training, the large increase in left hip extension post-training now exhibits an imbalance favoring the left side. Hip abduction strength displayed no increase for the right side and minimal increase for the left side. Adduction strength was significantly improved ($p = 0.036$, $d = 0.52$) for the right side by 14%, and similarly, but not significant, by 12% on the left side. In relation to flexion and extension about the knee, both left and right sides demonstrated equivalent strength increases, with flexion increasing by a slightly higher percentage. The training program proved to be successful in altering the overall strength of the participants.

Stop-Jump Task

For the stop-jump task, multiple statistically significant main effects were observed at IC, PKF, and Peak Stance (Tables 4, 5, and 6). At IC, there was a 3° change ($p = 0.007$, $d = 0.76$) observed as the knee moved from an abducted position pre-training to an adducted position. The hip also demonstrated a significant increase ($p = 0.007$, $d = 0.63$) in hip abduction angle, shifting from an adducted to an abducted position between pre- and post-training. The changes in other kinematic and kinetic variables from pre- to post-training at peak stance were not significant ($p > 0.05$).

At PKF, the training program only elicited a significant change ($p = 0.002$, $d = 0.99$) for the hip abduction angle. At both pre- and post-training, a hip abducted position was demonstrated, but post-training exhibited a 3.78° increase. Though not significant, it is important to note that the knee abduction angle decreased by 3° from pre-training to post-training. Kinetically, key changes were demonstrated in the knee flexion moment, increasing 17%, and knee abduction moment, shifting from an abduction moment to an adduction moment, from pre- to post-training ($p > 0.05$).

The training program influenced the maximal knee extension moment at peak stance significantly ($p = 0.027$, $d = 0.48$), displaying an 18% increase post-training. Though not significant, the training program also altered the knee abduction angle and moment at peak stance, decreasing the angle 3.78° and increasing the moment over two-fold. No other significant differences were found for the kinematic and kinetic variables during peak stance ($p > 0.05$).

DISCUSSION

The use and efficacy of neuromuscular training programs to prevent ACL injuries has been emphasized through multiple research studies. Such neuromuscular training programs demonstrate the ability to modify biomechanical factors associated with an increased risk of incurring a noncontact ACL injury (3, 8, 11, 14, 23, 29, 30). The current intervention emphasized the use of augmented feedback throughout the training program while performing resistance-training tasks, as well as speed, agility, and plyometric drills, and demonstrated the ability to bring about similar alterations in mechanics that are attributed to a lower incidence of suffering an ACL injury. The primary finding of this study was that a 10-week feedback inclusive neuromuscular training program altered knee and hip mechanics in the course of performing a dynamic stop-jump task. The feedback inclusive neuromuscular training program also brought about increases in isometric hip strength.

The intervention within this study consisted of a 10-week training program comprised of four sessions performed each week, overseen by a CSCS. Though the time commitment and skill level required for this training intervention may seem excessive for a practical application to all athletes, its utilization in the collegiate and elite level athletic realms is feasible. The intervention sessions, both the resistance and field conditioning, were designed to be completed in no more than one hours time, a relatively standard amount of time a strength coach is allotted to work with an individual team each day. The drills and lifts were chosen based upon the generalized skill level of an incoming collegiate freshman athlete. This increased the importance of having the CSCS present at the training sessions, ensuring that drills and lifts were being performed properly in regards to body positioning.

Strength training programs have been researched in their role for injury prevention (12, 22, 39), with studies demonstrating that reduced muscular strength can influence the risk of incurring a lower extremity injury (19, 21, 40).In relation to ACL injuries, reduced muscular strength can be deemed as an insufficiency or an imbalance about the hip or the knee. With regards to the knee, the relationship of the hamstrings to the quadriceps for muscular imbalance is of great concern, with females demonstrating greater imbalances (13). If an imbalance exists, with the quadriceps being disproportionate to the hamstrings, increased shear forces may occur at the ACL due to unwarranted anterior translation of the tibia during forceful activities. Within this study, an imbalance existed between the quadriceps and hamstrings at both pre- and post-training. Though not significant, the increase in hamstring strength post-training was greater than that of the quadriceps, facilitating a decrease in the muscular imbalance. Herman et al (11, 12) demonstrated similar changes, with significant increases for both the knee flexors and extensors through a strength-training program, but created an increase in the imbalance between the quadriceps and hamstrings. As the strength increases within the current study were diminutive, it cannot be speculated that the kinematic and kinetic changes demonstrated are attributed to any increased strength about the knee.

In relation to hip strength, Leetun et al demonstrated that hip abduction and internal rotation were weaker in females compared to males for athletes participating in running and jumping sports (21). This female deficiency in hip strength is further supported by a previous study from Jacob et al (17), who reported a moderate negative correlation for peak hip abductor torque related to peak hip flexion and adduction during a jump-landing task. Females are thought to rely more upon hip musculature during weight bearing activities, but do not have ample ability to produce muscular stiffness (40). This elucidates the importance of improving strength about the hip to reduce the risk of an ACL injury. The strength-training program within this study demonstrated significant improvements of muscular strength about the hip. Significant hip strength increases came about the hip flexors and adductors for the involved side in the current study, and it has been theorized that a strength imbalance of the anterior medial hip to the posterior lateral hip can have a detrimental effect on the ability to maintain hip stability, which further affects knee alignment (15). Though the anterior medial hip musculature, hip flexors and adductors, demonstrated an undesired increase, the kinematics during the task demonstrated contradictory findings with the hip shifting to a more abducted position throughout the movement. As the kinematics within this study differ from the theorized movement in relation to muscular strength and imbalances, this study supports the notion that strength-training alone would not be an effective method for reducing the risk of an ACL injury and puts a great emphasis upon the efficacy of the augmented feedback utilized during the training sessions. The findings from Mizner et al (26) support this theory, as their study exhibited weak correlations between isometric strength and kinematic changes at the hip and knee after feedback during a drop-jump task. That study revealed that regardless of initial isometric strength values, a single exposure of feedback can positively influence landing mechanics with regards to risk factors of an ACL injury. As isometric strength testing was used in this study, we must consider that isometric strength does not allow for any interpretation of what may be occurring within the dynamic state of the task which could attribute to the kinetic and kinematic changes that occurred, as rate of force development, activation patterns, and co-contractibility of the muscles in question could have been influenced by the strength training within this study. Further investigation into the role of muscular strength in preventing ACL injuries should be evaluated with consideration to what is occurring within the dynamic state of the task and how that can be adapted through strength training programs.

It was the aim of this study to bring about biomechanical changes through the implementation of a neuromuscular training program. The stop-jump task utilized in the current study has been researched previously (2, 11, 12, 41), and was selected for its relationship to the soccer-specific motion of “heading” a ball in flight. In relation to the risk of incurring an ACL injury, kinematics is the major focal point for risk factors and their alterations. It has been debated as to which plane of motion, frontal, sagittal, or transverse, has the greatest influence on the incidence of an ACL injury, with much of the recent literature focusing on the frontal plane. In viewing the kinematic adaptations within this study, frontal plane motions about the hip and knee were significantly altered. An initial contact with the knee in an abducted or valgus position has been noted as a biomechanical motion that can potentially increase the risk of suffering an ACL injury (7). Altering this to a knee adducted position at initial contact potentially reduces the risk of incurring an ACL injury; as well, increasing the hip abduction angle decreases the ability of the knee to assume an abducted position. The results of this study demonstrated significantly greater knee adduction and hip abduction post-training. The change in the knee abduction angle at initial contact from a valgus position pre-training to a varus position post-training, differs from the results presented by Chappell and Limpisvasti (3). The female collegiate athletes within their study demonstrated a larger valgus position pre-training, with an increased valgus position post-training. That study also demonstrated a decrease in hip abduction at initial contact from pre- to post-training, which is incongruous to the increased hip abduction at initial contact in the current study. It is theorized that the differences noted between that study and the current study could be caused by the lack of feedback provided to the subjects during the intervention, as well as the use of a generalized training program. The subjects in that study received demonstrations of the tasks at only the initial session, and then performed the tasks for six weeks without knowledge of their performance. This theory can be supported by the study from Myer et al (29), in which a comprehensive neuromuscular program was utilized that provided feedback during the training sessions. That study utilized a vertical drop-jump task, but provided changes similar to the current study in frontal plane hip and knee angles at initial contact. Previous studies (18, 32) have demonstrated that females tend to make initial contact with less hip abduction in comparison to males during a stop-jump task, and this has been speculated to be caused by a deficiency in hip abduction and rotation strength (21). As this study encompassed a strength component, it must be noted that no significant difference was found post-training for isometric hip abduction strength. Witnessing the increased hip abduction without an increase in isometric hip abduction strength does not discount the importance of muscular strength in maintaining proper mechanics during a stop-jump task. It has been suggested that a decreased hip abduction angle during a stop-jump task could be the result of poor eccentric control of the hip abductor muscle (21), which could not be analyzed through the use of isometric testing in this study. At a position of peak knee flexion, a significant increase was once again noted for the hip abduction angle. An increased hip abducted position while the knee is flexing will keep the knee from moving into a position of abduction by limiting femoral internal rotation, having a protective effect in decreasing the risk of incurring an ACL injury. As jump-landing techniques were utilized during the field training sessions of the intervention, the augmented feedback employed mimicked the demonstrated changes in the kinematics. Flexion about the hips, knees, and ankles, as well as frontal plane positions, were emphasized during jumping, running, and cutting tasks, and were immediately corrected or praised by the CSCS. Not all studies utilizing neuromuscular interventions have proven to alter kinematics, but previous studies utilizing augmented feedback (11, 25, 26, 31) have found similar alterations in knee and hip kinematics in relation to protective mechanisms for reducing the risk of incurring an ACL injury. As the scope of augmented feedback in reducing ACL injuries is currently limited, it is suggested that further investigation into its efficacy of injury prevention is warranted.

The forces generated by and within the lower extremity are also of concern when considering risk factors for ACL injuries, and it was within the scope of the neuromuscular training program to bring about alterations within these kinetic variables. An increase in the knee extension moment was displayed at peak stance. As peak knee extension moment has been shown to increase peak proximal tibia anterior shear force (35), this is counterproductive to decreasing the risk of ACL injuries. As the increase at peak stance in the study occurred after the peak posterior ground reaction force, its implication on an ACL injury may not be as severe, as previous studies have noted its influential effect at the occurrence of the peak posterior ground reaction force (35). As well, the initial value and increase displayed is comparative to previously demonstrated values (18). It can be hypothesized that through neuromuscular training, larger forces can be attenuated through musculature and altered kinematics, and subsequently this will not increase the risk of suffering an ACL injury. Though the training program provided feedback and emphasized “soft” landings, it was unable to demonstrate any significant decreases in ground reaction forces or joint moments. As these are highly trained collegiate athletes, it may be hard to bring about the most minute changes, both kinetically and kinematically, and therefore the absolute effectiveness of the training program is unknown.

As an experienced CSCS was utilized to perform the intervention, it must be discussed that previous knowledge in movement skills and augmented feedback may have influenced the implementation of the training protocol within this study. Having specific prior knowledge in movement skills allows for the teaching of efficient movement patterns regardless of the drill chosen, and therefore it should be recognized that the drills chosen for the intervention may be arbitrary in relation to the feedback given related to the quality of movement patterns. This expertise must be accounted for when implementing any injury prevention protocol, in the fact that the movement quality produced will be directly influenced by the individual providing the augmented feedback, not the task that is chosen.

Limitations within the current study warrant reservations when interpreting the results. The inadequate and unbalanced group sizes limit the ability to differentiate alterations between resistance training groups. These groups also lacked randomization, as they were pre-assigned by the coaching staff prior to the initiation of the study, and were based on morphological expectations of the coaching staff. The lack of a control group in the study also limited the ability to quantify the changes solely brought about by the intervention. Many collegiate soccer teams already perform speed, agility and plyometric drills as part of their practice regimen, therefore, the changes could possibly be brought about due to the consistent repetition of performing a specific drill, regardless of feedback and strength factors. Due to the required time component, the implementation of this program is limited to the scope of collegiate and professional athletic teams.

A neuromuscular training program consisting of resistance training and field training, coupled with augmented feedback significantly affected the kinematics and kinetics of female collegiate soccer players. Significant increases were also apparent for isometric hip strength. Changes in hip abduction and knee adduction angles demonstrate the protective mechanisms brought about by this intervention in relation to the risk of an ACL injury within a population that is greatly exposed to the possibility of incurring such a traumatic injury. Future studies investigating the use of such an intervention with a control group, as well as its implementation over longer time periods are needed. Future studies that encompass other genders and sports are needed as well.

PRACTICAL APPLICATIONS

As the outcome of this study showed positive results in altering hip and knee mechanics in relation to reducing the risk of incurring an ACL injury, this study demonstrates the ability to combine injury prevention programs with current strength and conditioning protocols. As many strength and conditioning specialists may be limited in the time they are allotted to work with individuals or athletic teams, both injury prevention and performance enhancement can be focused on concurrently. The use of augmented feedback to relay knowledge of performance to the athlete demonstrates the importance of a knowledgeable coach in relation to movement quality. As it is a primary responsibility of a strength and conditioning specialist to understand efficient movement, the application of relaying quality feedback to an athlete should be of the utmost importance during field and weight-room training sessions, not only for performance enhancement, but also to reduce the risk of injury.

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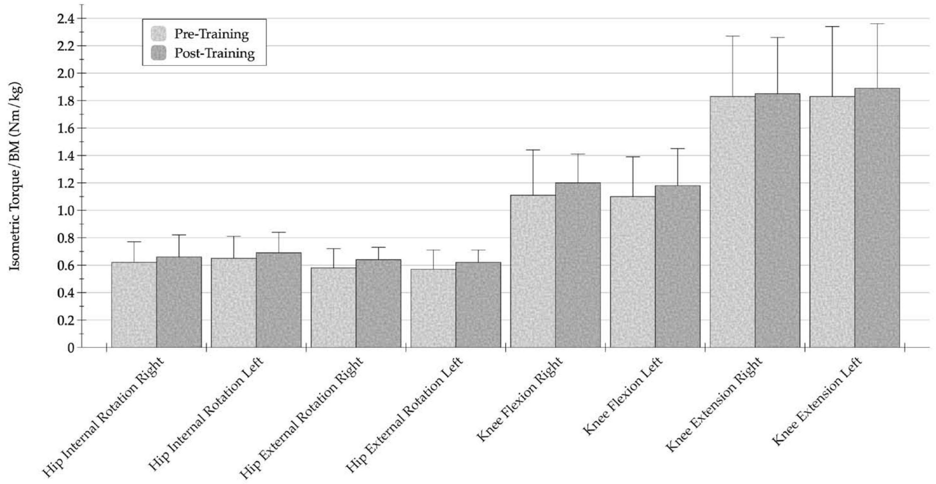

Figure 1.

Normalized Peak Isometric Strength for Seated Tests

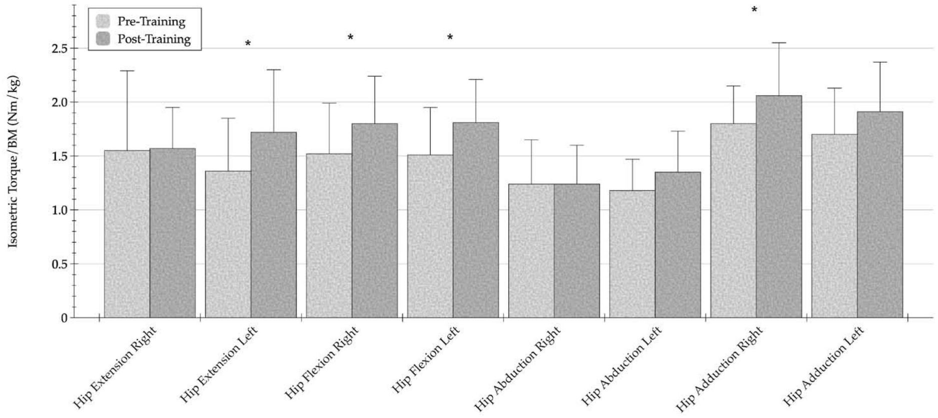

Figure 2.

Normalized Peak Isometric Strength for Standing Tests

Table 1

Participant Age, Height, and Weight (Mean ± SD)

	STR Group	MNT Group	END Group
Age Pre-training (y)	19.25 ± 0.96	19.40 ± 0.89	18.67 ± 0.58
Height Pre-training (m)	1.66 ± 0.22	1.69 ± 0.77	1.66 ± 0.66
Weight Pre-training (kg)	56.45 ± 1.97	64.60 ± 3.65	63.63 ± 2.83
Weight Post-training (kg)	56.27 ± 2.48	59.22 ± 10.30	67.97 ± 4.28

Table 2

Resistance training exercises and volume for the STR and END groups

	Exercise	Resistance-training Group (repetitions × 3 sets)
Weeks 1, 2, 5, 6, 9, & 10	STR	END
Monday		
DB Single Arm Power Clean	6/arm	6/arm
BB Power Jerk	6	6
BB Front Lunge	10/leg	15/leg
Stiff-leg Deadlift	12	20
Back Squat	10	20
BB Bent-Over Row	12	20
Dips - assisted	8	16
Medicine Ball Side Toss	10/side	10/side
Basket Hangs	12	12
Planks - 3 way × 30 sec		
Wednesday		
BB Hang Clean	10	10
DB Single Arm Jerk	6	6
Box Jumps	6/arm	6/arm
Russian Hamstring Extension	10	16
Front Squat	12	20
Pull-ups - assisted	8	16
DB Incline Chest Press	12	20
Roman Chair Hyperextension	12	16
Roman Chair sit-ups	12	16
Weeks 3, 4, 7, & 8		
Monday		
DB Single Arm Power Clean	6/arm	6/arm
BB Power Jerk	4	4
BB Front Lunge	8/leg	15/leg
Stiff-leg Deadlift	10	20
Back Squat	8	20
Inverted Row	Max	Max
MB Push-ups	10	16
Cable Chops	10/side	10/side
Medicine Ball Around the World	4/direction	4/direction
Planks - 3 way × 45 sec		
Wednesday		
BB Hang Clean	6	6

	Exercise	Resistance-training Group (repetitions × 3 sets)
DB Single Arm Jerk	6/arm	6/arm
Box Jumps	10	10
Russian Hamstring Extension	10	16
Overhead Squat	8	16
Pull-ups - assisted	8	16
Plyometric Clapping push-ups	Max	Max
Roman Chair Hyperextension	12	16
Roman Chair sit-ups	12	16

Table 3

Weekly field-conditioning drills

		Tuesday		Thursday	
Dynamic Warm-up		**Speed / Quickness**		**Plyometrics**	
Light Jog	40m × 4	Fast Feet	6 sec × 4	Tuck Jumps	10 reps × 2
Leg swings right	10 reps	Falling accelerations	20m × 4	Star Jumps	10 reps × 2
Leg swings left	10 reps	Get-up starts - face down	20m × 4	Lateral Hops	10 reps × 2
Leg swings across body right	10 reps	Ins and Outs	60m × 4	Split-squat jumps	10 reps × 2
Leg swings across body left	10 reps	Flying 40’s	60m × 2		
Skips	20m × 2	Wall Drills		Agility	
Butt kicks	20m × 2	single drive	10 reps/leg		
Sprint 50%	20m × 2	double drive	6 reps/set	1 Step Crossovers	10 reps × 2
Scorpions	10/side	triple drive	4 reps/set	3 line drill w/ stick	5 reps/side × 2
Eagles	10/side			Agility ladders	
Stiffleg bounds	20m × 2			1 foot/box	2 reps
High knees	20m × 2			2 feet/box	2 reps
Sprint 75%	20m × 2			In-In-Out-Out Forward	2 reps
Hamstring rollovers	10/side			In-In-Out-Out Lateral	2 reps
Crossover toe touches	5 reps			Shuffle	2 reps
Carioca - facing same dir	20m × 2			Pro-agility	5 reps
Carioca w/ knee drive	20m × 2			T-drill	3 reps
Backpedal	20m × 2			NFL 3-cone turn	4 reps
Backpedal w/ extension	20m × 2				
Sprint 100%	20m × 4				

Table 4

Hip and Knee Kinematics and Kinetics at Initial Contact

Variable	Pre-Training Mean ± SD	Post-Training Mean ± SD	P
Knee Flexion, deg	−27.45±8.82	−24.10±6.63	0.187
Knee Abduction[b], deg	−1.48±3.65	1.46±3.86	0.007
Knee Rotation, deg	8.65±8.82	7.90±6.64	0.648
Knee Flexion Moment, Nm/BM[a]	0.07±0.21	0.13±0.23	0.533
Knee Abduction Moment, Nm/BM[a]	0.03±0.06	0.04±0.08	0.696
Hip Flexion, deg	53.94±6.72	55.52±9.78	0.664
Hip Abduction[b], deg	−6.05±4.63	−10.34±6.83	0.007
Hip Rotation, deg	2.77±9.05	3.91±7.40	0.725
Hip Flexion Moment, Nm/BM[a]	0.08±0.24	0.18±0.32	0.418
Hip Abduction Moment, Nm/BM[a]	0.07±0.15	0.10±0.15	0.397

[a] - BM, Body mass (kg)

[b] - (−) abduction/ (+) adduction

Table 5

Hip and Knee Kinematics and Kinetics at Peak Knee Flexion

Variable	Pre-Training Mean ± SD	Post-Training Mean ± SD	P
Knee Flexion, deg	−60.30±7.71	−59.13±8.87	0.187
Knee Abduction[b], deg	−4.94±6.37	−1.69±5.98	0.205
Knee Rotation, deg	14.12±5.59	17.10±4.70	0.067
Knee Flexion Moment, Nm/BM[a]	1.67±0.35	1.96±0.76	0.051
Knee Abduction Moment, Nm/BM[a]	0.14±0.20	−0.07±0.34	0.079
Hip Flexion, deg	50.78±9.91	52.87±12.68	0.464
Hip Abduction[b], deg	−2.23±3.40	−6.01±3.82	0.002
Hip Rotation, deg	−0.36±8.13	0.70±7.30	0.761
Hip Flexion Moment, Nm/BM[a]	−0.19±0.29	−0.05±0.58	0.326
Hip Abduction Moment, Nm/BM[a]	−0.29±0.20	−0.29±0.33	0.99

[a] - BM, Body mass (kg)

[b] - (−) abduction/ (+) adduction

Table 6

Hip and Knee Kinematics and Kinetics at Peak Stance

Variable	Pre-Training Mean ± SD	Post-Training Mean ± SD	P
Hip Flexion, deg	58.79±8.21	60.65±10.46	0.543
Knee Abduction[b], deg	−6.28±4.73	−2.50±5.55	0.052
Maximum Knee Extension Moment, Nm/Bm[a]	2.02±0.32	2.38±0.75	0.022
Maximum Knee Flexion Moment, Nm/Bm[a]	−0.26±0.22	0.07±0.25	0.247
Maximum Knee Adduction Moment, Nm/BM[a]	0.35±0.11	0.24±0.17	0.067
Maximum Knee Abduction Moment, Nm/BM[a]	−0.19±0.21	−0.40±0.29	0.076
Maximum Hip Flexion Moment, Nm/BM[a]	0.55±0.35	0.80±0.75	0.257
Maximum Hip Extension Moment, Nm/BM[a]	−2.02±0.53	−2.19±0.65	0.334

[a] - BM, Body mass (kg)

[b] - (−) abduction/ (+) adduction