International Journal of Applied Sports Sciences
2021, Vol. 33, No. 2, 119-130.
https://doi.org/10.24985/ijass.2021.33.2.119

ISSN 2233-7946 (Online)
ISSN 1598-2939 (Print)

The Effect of an 8 Week Neuromuscular Training Program on Knee Movement Biomechanics in African American Female Athletes

Timothy W. Hughley[a], Joyce Johnson[b], Kevin R. Ford[c,d,e], & Aram Yoon[a*]
[a] *Darton College of Health Profession, Department of Health & Human Performance, Albany State University, Albany, Georgia, USA*
[b] *Darton College of Health Profession, Department of Nursing, Albany State University, Albany, Georgia, USA*
[c] *Department of Physical Therapy, School of Health Sciences, High Point University, High Point, North Carolina, USA*
[d] *Division of Sports Medicine, Cincinnati Children's Hospital Medical Center, Cincinnati, Ohio, USA*
[e] *Department of Pediatrics and Orthopedic Surgery, University of Cincinnati, Cincinnati, Ohio, USA*

Abstract

This study examined the effects of an eight-week neuromuscular training (NMT) program on knee valgus angle in African American female athletes. Twenty-six female collegiate athletes participated. NMT group (n=15, 19.6±1.12 years) underwent an intervention training program that included three main components (plyometric and movement, core strengthening and balance, and resistance training). While, control group (n=11, 19.3±1.50 years) underwent the resistance training protocol for eight weeks. We hypothesized the NMT program would significantly decrease knee valgus angles during a drop vertical jump (DVJ) at landing for the NMT group when compared to the control group. Wilcoxon signed rank tests were done on the Pre-and Post-test findings. Results showed maximum valgus angle (VGmax) is significantly decreased ($p<.05$), and Maximum flexion (Flexmax) is significantly increased during the drop vertical jump in dominant leg ($p<.05$). The results support the hypothesis that an 8-week NMT program that combines injury prevention-training components can decrease an injury risk factor such as knee valgus in African American female athletes.

Key words: neuromuscular training, kinematics, valgus, anterior cruciate ligament (ACL) injury, African American athletes

Introduction

Female athletes are currently reported to be 4 to 6 times more likely to sustain a sports related non-contact ACL injury than male athletes in comparable high-risk sports (Agel, Rockwood, & Klossner, 2016; Myer, Chu, Brent, & Hewett, 2008; Nessler, Denney, & Sampley, 2017). Altered or decreased neuromuscular control during the execution of sports movements, which result

---

Submitted : 28 April 2021
Revised : 5 October 2021
Accepted : 14 December 2021
Correspondence : aram.yoon@asurams.edu

in excessive resultant lower limb joint motions, may increase risk of anterior cruciate ligament (ACL) injury in female athletes (Levins et al., 2017; Myer, Ford, Palumbo, & Hewett, 2005; Petushek, Sugimoto, Stoolmiller, Smith, & Myer, 2019). Previous research has reported that female athletes landed with greater total knee valgus motion and a greater maximum knee valgus angle than male athletes (Ford, Myer, & Hewett, 2003). Female athletes also had significant differences between their dominant and non-dominant side in maximum knee valgus angle. These differences may also be risk factors for sports-related injury.

Neuromuscular and biomechanical characteristics are considered to be contributing factors related to female ACL injuries that have received considerable attention in recent years (Nedergaard, Dalbo, Petersen, Zebis, & Bencke, 2020). In part, the focused attention on neuromuscular and biomechanical factors is due to their potential for modification through injury prevention programs (Lephart et al., 2005). Injury prevention programs have been developed to modify specific neuromuscular and biomechanical characteristics in an attempt to reduce the number of ACL injuries in female athletes (Hewett, Ford, Xu, Khoury, & Myer, 2017; Lephart et al., 2005; Myer et al., 2005; Scarborough et al., 2019).

Hewett et al. (2005) conducted a systematic review which included six studies that were designed to identify the effectiveness of training interventions to prevent knee injuries during athletics. The results of this study revealed that there appears to be a measurable effect of neuromuscular training interventions on knee, and more specifically, ACL injury risk. The intervention used in the Hewett et al study was designed to focus on correction of dynamic movement patterns and muscle imbalances, and used technique training and lower body plyometrics with supplemental strength training (Hewett et al., 2005; Hewett, Stroupe, Nance, & Noyes, 1996; Mandelbaum et al., 2005). Trained athletes demonstrated significant biomechanical effects of neuromuscular training on landing mechanics in female athletes (Hewett et al., 2005). Myer et al. (2005) conducted a comprehensive neuromuscular training program designed for the prevention of lower-extremity injuries. Subjects who underwent the 6-week protocol in this study were able to improve measures of vertical jump, single-leg hop distance, speed, bench press, squat, knee range of motion (ROM), and knee varus and valgus torques compared with their pre-training values and compared with an untrained control group. The demonstrated improvements were both statistically and clinically (functionally) significant (up to 92% improvement). Coach-led neuromuscular warm-up reduces lower extremity (LE) injuries in female athletes in a mixed-ethnicity, pre-dominantly low-income, urban population (LaBella et al., 2011).

According to the previous study, ACL tear rates vary by racial group, and African American female (AAF) athletes were significantly different in intercondylar notch width (Shelbourne, Gray, & Benner, 2007; Trojian & Collins, 2006). These evidences imply that AAF athletes might have different neurotraining effect on knee movement biomechanics. However, there appears to be limited data investigating neuromuscular training prevention programs in AAF athletes. There was in fact limited evidence in each of the above studies, or other literature reviewed, that African American female athletes were represented in neuromuscular training prevention efforts.

To the best of our knowledge, no study has reported the effect of a neuromuscular training program on knee valgus angles in African American female athletes. To address the apparent gap in the literature investigating AAF athletes and neuromuscular training prevention programs, this study examined the effect of an 8 week neuromuscular training program on lower extremity neuromechanics, specifically knee valgus angle measures related to injury risk in AAF athletes.

Methods

Experimental Approach to the Problem

An experimental design was used to quantify the effects of a neuromuscular training intervention on subjects in this study. Control and experimental subjects were pretested one week before the initial training session. An abbreviated pilot study was completed to test the procedural processes. During subsequent implementation of the full study, post-testing was performed approximately nine weeks after pretesting on the control group and experimental subjects were tested at eight weeks. One certified strength and conditioning specialist and one certified athletic trainer conducted all testing and training. Experimental subjects were trained in two groups, in identical training sessions on different dates. The Rocky Mountain University of Health Professions and Albany State University Institutional Review Boards approved this study prior to implementation of the pilot or study.

Subjects

Twenty-six female National Collegiate athletes from a Division II University participated in this study. The subjects were asked to list their primary sport; 8 reported track, 9 reported volleyball, and 9 reported softball. Participants gave informed consent before the subjects' participation in the study. Fifteen subjects were assigned to the intervention group and eleven subjects were assigned to the controlled group. Information about the subjects can be found in Table 1.

Table 1. *Descriptive data on participants*

Variables	RT (n=11)	NMT (n=15)
Age (years)	19.4±1.50	19.6±1.12
Height (cm)	164.9±6.49	167.2±6.72
Weight (kg)	60.3±8.08	82.3±16.81
Body Fat %	20.5±2.60	29.62±6.33
BMI	22.1±1.86	29.6±6.61
Tibia Length (cm)	38.8±1.82	38.4±2.16

RT: Resistance Training control, NMT: Neuromuscular training intervention. Data are means±SD.

Experimental Procedures

Two-dimensional frontal and sagittal plane knee kinematic data was captured with standard video cameras (Canon XL2 3CCD DV) with an effective sampling rate of 60 Hz. The cameras were levelled and positioned at a height of 80 cm, perpendicular to each other in the frontal and sagittal planes (Myer, Ford, & Hewett, 2011). The box (31 cm high), used for the drop vertical jump (DVJ) was centered on the frontal camera view and approximately 30 cm off center of the sagittal plane view away from the camera in the frontal plane position. Prior to the DVJ test performance, a standardized target was placed overhead, equal to the subject's maximal touch height during the countermovement vertical jump. The subjects were instructed to stand on top of the box with their feet positioned 35 cm apart, as shown in (Figure 1, A). Once prepared, the subjects dropped directly down off the box and immediately performed a maximum vertical jump, raising both arms towards the overhead target. Subjects were allowed one to three practice trials to ensure they were able to demonstrate adequate understanding and ability to perform the instructed test maneuver (Myer et al., 2011).

Data were collected by two video views synchronized with Dartfish Motion Analysis software, (Alpharetta, GA) and imported them to freeware software ImageJ (Rasband W S, ImageJ, US National Institutes of Health, Bethesda, Maryland, USA, http://rsb.info.nih.gov/ij/, 1997-2009) to digitize the images. Four image files were captured in the following order: - frontal plane view with frame prior to initial contact, -frontal plane view of frame with knee in maximum medial (valgus) position, - Sagittal plane view with frame prior to initial contact, - Sagittal plane view of frame with knee in maximum flexion position and named in a standard structure for each subject (i.e., SubjectX , SubjectX , SubjectX , SubjectX) figure 1 B), C) (Myer et al., 2011). The digitized hip, knee and ankle marker coordinates were exported to Excel. Valgus and flexion angles were calculated based on the relationship of the tangent for each image.

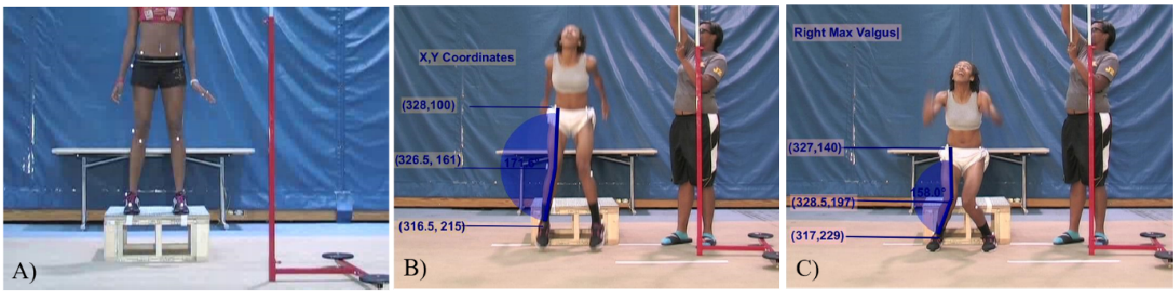

Figure 1. *Valgus and flexion angles calculation*

A) Drop Vertical Jump. B) Frame Prior to Initial Contact. C) frontal plane view with knee in maximum medial (valgus) position.

Training Procedures

The neuromuscular training program used in this study was a synthesis of findings derived from published research studies and prevention techniques (Caraffa, Cerulli, Projetti, Aisa, & Rizzo, 1996; Griffin et al., 2000; Heidt, Sweeterman, Carlonas, Traub, & Tekulve, 2000; Hewett, Lindenfeld, Riccobene, & Noyes, 1999; Hewett et al., 1996; Kraemer, Duncan, & Volek, 1998; Myer et al., 2005). The components of the dynamic neuromuscular training protocol utilized in this study included plyometrics and movement training, core strengthening, balance training, and resistance training (Myer et al., 2005). The training program was conducted on Monday, Wednesday, and Friday. Each training session lasted for approximately 90 minutes. Before each training session, an active warm-up that included jogging, backwards running, lateral shuffling, and carioca was used. Monday training included a 30-minute plyometric station, a 30-minute strength station, and a 30-minute core-strengthening and balance station. Wednesday training included a 30-minute plyometric station, a 30-minute speed station and a 30-minute strengthening and balance station. Friday training included a 45-minute strength station and a 45-minute speed station. At the end of each training session, the subjects performed self-selected stretching exercises for 15 minutes. The training session

Table 2*. Example of plyometric and movement-training component from 2 session*

Exercise	Sets	Time or repetitions (reps)
Wall jumps (ankle bounces)		15s
Squat jumps (frog jumps)	1	10s
Barrier jumps (front to back speed)	1	10s
Barrier jumps (side to side) speed	1	15s
Crossover hoop, hop, hop, stick (right to left)	1	6 reps
180^0	1	15s
Broad jump, jump, jump, vertical	1	6 reps
Jump into bounding	1	6 reps
Forward barrier hops with staggered box	1	6 reps
Lateral barrier hops with staggered box	1	6 reps
Box depth-180^0-box depth max vertical	1	8 reps
BOSU 180^0 jumps stick landing	1	15 reps

was designed to last for a total of 8 weeks (Myer et al., 2005).

The plyometrics and dynamic-movement training component progressively emphasized double-then single-leg movements throughout training sessions (Hewett et al., 1996). The majority of the initial exercises involved both legs to safely introduce the subjects to the training movements. Early training emphasis was on sound athletic positioning that may help create dynamic control of the subject's center of gravity (Myer et al., 2005; Myklebust et al., 2003). Soft, athletic landings that stressed deep knee flexion were used by the trainer, with verbal feedback to make the subject aware of biomechanically unsound and undesirable positions. Progressively, a greater number of single-leg movements were introduced while the focus on correct technique was maintained.

The resistance training component was progressed from an initial high-volume and low-intensity protocol to a low-volume and high-intensity protocol (Table 3). Exercise order progressed from multi-joint exercises to alternating upper and lower-body exercises. Trainers prescribed the weight to be used before each session for each subject. The subjects recorded the number of repetitions achieved after each completed set. The weight to be used was increased before each training session if the required number of repetitions was achieved to ensure appropriate intensity progression (Myer et al., 2005).

The core strengthening and balance training component of the protocol (Table 4) followed an organized exercise selection specifically directed at strengthening the core stabilizing muscles. This component focused on providing an appropriate balance between developing the proprioceptive abilities of the subject and exposing the subject to inadequate joint control. The training progression took the subject through a combination of low- to higher-risk maneuvers in a controlled situation. The intensity of the exercises was modified by changing support stance, increasing or decreasing surface stability with balance training device (BOSU Balance Trainer, DW Fitness LLC, Madison, NJ), increasing or decreasing speed, adding unanticipated movements or perturbations, and adding sports-specific skills (Myer et al., 2005).

Statistical Analysis

Demographic data were aggregated with means and standard deviations determined for each characteristic for the resistance training control and neuromuscular training intervention group. Statistical means and standard error of the mean for each variable were calculated for each subject. Wilcoxon signed rank tests

Table 3. *Example of resistance-training component from 1 session*

Exercises	Sets	Repetitions
DB Hang snatch	2	8
Squat	2	8
Bench press	2	8
Leg curl	2	8
Shoulder press	2	8
Lat pull-down	2	8
Assisted Russian hamstring curl	2	15
Back fly	2	12
Bicep circuit	1	12
Ankle plantar-dorsi	1	12

Table 4. Example of core strength and balance-training component

Exercises	Sets	Time or repetitions (reps)
Broad jump-stick	1	4 reps
Crossover hop-stick	1	12 reps
Single-leg x hop	1	5 reps
Box drop Medicine ball catch	1	8 reps
180 jumps stick landing-medicine ball catch	1	6 reps
BOSU double-leg perturbations	2	20 s
BOSU both knees deep hold-medicine ball catch	2	20 reps
BOSU double-leg pick	1	10 reps
BOSU single-leg deep hold	2	20s
BOSU crunches	1	55s
Double crunch	2	25 reps
BOSU V-wit-toe touches	1	15 reps
BOSU swivel crunch (feet up)	2	30 reps
BOSU superman (right to left)	1	20 reps

were used to compare pre- and post-test values for the control and intervention groups to determine statistical significance. Statistical analyses were conducted in SPSS (SPSS for Windows, Release 21, SPSS Inc., Chicago, IL). The level of significance was set at $P < 0.05$. The pre-established compliance criterion required that each participant be present for at least two-thirds (16 of 24) of the training sessions to be included in the study.

Results

The study subjects demonstrated significant biomechanical changes during a landing maneuver after the 8-week neuromuscular training intervention. Measurements taken from the subjects with 2-dimensional motion analysis were used to calculate the knee flexion range of motion during landing from a box DVJ.

Current research hypothesized the neuromuscular training program would significantly decrease lower extremity knee valgus angles during a drop vertical jump at landing compared to the resistance training control group. The results of valgus angels at each state of the landing are presented in table 5.

No statistically significant difference was found in knee initial contact valgus angles from the initial measurement to the end of the intervention period for the intervention group (pre mean = 6.22±3.629, post mean = 5.12±3.603), p=0.134, or the resistance training control group (pre mean = 4.71±3.278, post mean = 3.53±3.918), p=0.157.

The intervention group’s post training mean (5.84±13.766) demonstrated a 9.4 degree statistically significant decrease (p=0.005) in valgus angle from pre-test while the control group’s mean (15.75±18.437) at the end of the period represented only a 0.6-degree non-significant decrease in knee valgus angle from the pre-test period to the reassessment period eight weeks later. Neuromuscular training intervention subjects demonstrated a significantly lower magnitude of knee valgus angle at post-test when compared to the pre-training period, while the control subjects had no significant change.

Table 5. *Valgus angles at each stage of the landing*

Variables	RT (n=11)			NMT (n=15)		
	Pre	Post	*p*	Pre	Post	*p*
VG at IC_R	2.35±4.954	3.24±3.811	.722	3.47±3.765	1.73±7.920	.534
VG at IC_L	2.31±4.398	0.59±4.657	.286	5.34±4.489	4.14±4.223	.475
VGmax_R	10.21±18.582	9.66±24.154	.790	9.85±11.410	1.44±17.564	.182
VGmax_L	7.70±15.288	5.39±12.760	.594	7.56±11.579	0.46±14.505	.213
VG ROM_R	16.83±8.305	20.08±12.321	.534	8.84±7.735	11.99±8.951	.594
VG ROM_L	12.32±8.689	9.31±9.400	.286	7.97±7.490	8.84±9.719	.859
Flex at IC	16.02±8.688	16.40±10.971	.999	17.86±7.655	17.14±11.270	.286
Flex ROM	71.67±14.525	70.12±6.729	.999	57.13±13.119	61.35±15.058	.772

RT: Resistance Training control, NMT: Neuromuscular training intervention. Data are means ± SD.
VG at IC_R: Right Valgus angle at Initial Contact, VG at IC_L: Left Valgus angle at Initial Contact, VGmax_R: Right maximum Valgus angle, VGmax_L: Left maximum Valgus angle, VG ROM_R: Right Valgus Range of Motion, VG ROM_L: Left Valgus Range of Motion, Flex at IC: Flexion angle at Initial Contact; Flex ROM: Flexion Range of Motion during the landing
*** Significant differences for p≤ .05**

Table 6. *Maximum Valgus angle and flexion at the initial contact and maximum point during the drop vertical jump in dominant leg*

Variables	RT (n=11)			NMT (n=15)		
	Pre	Post	*p*	Pre	Post	*p*
VGmax at IC	4.71±3.278	3.53±3.918	.131	6.26±3.762	5.13±3.739	.929
VGmax	15.12±13.867	15.75±18.437	.929	15.04±9.707	6.42±14.091	.018*
Flexmax	87.69±11.256	86.52±7.754	.859	74.99±7.655	78.49±6.478	.013*

RT: Resistance Training control, NMT: Neuromuscular training intervention. Data are means ± SD.
VGmax at IC: maximum Valgus angle at Initial Contact, VGmax: maximum Valgus angle of dominant leg, Flexmax: maximum Flexion during the landing
*** Significant differences for p≤ .05**

Maximum knee flexion ROM increased significantly from 74.79± 7.418° to 78.54±6.244° ($p < 0.05$). However, the resistance training control group demonstrated a no significant changes.

Discussion

The purpose of this study was to investigate the effect of an 8-week neuromuscular training program on lower extremity neuromechanics, specifically knee valgus angle measures related to injury risk in AAF athletes.

The high prevalence of ACL injuries in female athletes is thought to originate from various factors, such as hormonal, neuromuscular, and structural differences. African Americans have statistically significantly wider intercondylar notch widths on 45° flexed weightbearing posteroanterior radiographs than whites of the same gender (Shelbourne et al., 2007). It implies the difference between sexraces with regard to risk of ACL injuries. However, there is limited data on AAF athletes relative to injury and injury risk prevention. To our knowledge, no study has reported the effect of a neuromuscular training program on knee valgus angles in African American female (AAF) athletes.

The comprehensive neuromuscular training program for this study was designed for the prevention of lower-extremity injuries, that included plyometrics, movement training, core strengthening, balance training, and resistance training. This was shown to be effective in reducing the risk of noncontact knee ligament injuries and improving movement biomechanics in female athletes (Hewett, Ford, Hoogenboom, & Myer, 2010). Drop vertical jump is widely used as an evaluation and screening tool that simulates the biomechanics of landing. Previous researches have reported sex-based differences in the DVJ or similar landing tasks, with differences existing in biomechanical aspects, such as knee flexion, valgus, and normalized vertical ground reaction force (Hewett, Myer, & Ford, 2004; Hewett et al., 2005; Hughley, Ford, Myer, Johnson, & Yoon, 2019; Kawaguchi et al., 2021).

AAF's who underwent an 8-week neuromuscular training program in this study demonstrated no statistically significant differences in the valgus angles at each stage of the landing (table 5). According to the previous research, neuromuscular control deficit in female athletes increase lower extremity joint loads during sports (Hewett et al., 1996). One of the risk factors of neuromuscular control deficit is leg dominance. Because of the imbalance between tow lower extremities in strength, coordination and control, female athletes have high rate of ACL injuries. In this study, we could not find the improvement in right and left leg. Therefore, data were reorganized according to participants dominance. An 8-week neuromuscular training program in this study demonstrated statistically significant improvement in knee landing biomechanics in dominant leg, while no significant change was noted with the resistance training control group. The demonstrated improvements in maximum valgus angles were statistically significant. Additionally, maximum flexion angles in dominant leg were found to have decreased at a statistically significant level from the initial to the post-training period in the AAF intervention group. Kovacs and colleagues reported majority of subjects were landed on their dominant leg during the neuromuscular training program(Kovacs, Birmingham, Forwell, & Litchfield, 2004). It provides the supportive evidences to this current results. These results support the previous research of Myer et al, who used a neuromuscular training program design that focused on correction of dynamic movement patterns and muscle imbalances with technique training and lower-body plyometrics with supplemental strength training (Myer et al., 2005). Myer and colleagues disclosed that female athletes who participated in neuromuscular training revealed greater dynamic knee stability than did women who had not undergone training. Correspondingly, Hewett et al. performed an epidemiologic study with the purpose of prospectively evaluating the effects of the same neuromuscular training program on serious knee injury rates in female athletes (Hewett et al., 1999). The results revealed that technique-oriented plyometrics with supplemental resistance training significantly decreased serious knee injuries, including ACL tears. The previous research of Myer and colleagues provides a portion of the groundwork for the protocol used in the current study and the findings in these earlier studies are consistent with those found in the current study with AAF (Myer et al., 2005).

Authors have proposed that females tend to land from a jump with less knee flexion than males. The extended knee joint component of the injury mechanism relates to a neuromuscular imbalance that occurs in females that the authors term quadriceps dominance (Hewett et al., 2010). The results of the present study demonstrate that neuromuscular training that emphasizes deep knee flexion landings and stability exercises significantly alters knee biomechanics, specifically knee flexion, during the landing phase of a jump in AAF athletes. Griffin reports the work of Henning who identified 3 potentially dangerous maneuvers in sports that should be modified through training to prevent ACL injury (Griffin et al., 2000). He suggests that athletes land in a more bent-knee position and decelerate before a cutting maneuver. Preliminary work implementing the different techniques on a small sample of athletes suggested a decrease in injury rates between the trained and the untrained study groups. Boden et al support Henning's work with a biomechanical analysis with knee injuries in which they reported a majority of ACL injuries occur when landing and cutting with the knee near extension (Boden, Dean, Feagin, & Garrett, 2000). The potential injury prevention through improved movement mechanics substantiate the concept that deep knee flexion exercises should be incorporated into athletic-development training protocols. Deep knee flexion exercises were incorporated in the present study. The results of the current study revealed AAF athletes significantly increased deep knee flexion from pre to post training measurements. These findings indicate that AAFs may benefit from training protocols just as subjects in the previous studies benefitted from training protocols. Similar to the results demonstrated in Scarborough et al. (2019), the subjects showed simultaneous improvements in drop vertical jump.

An additional finding in this study was that African American females who participated in the neuromuscular training demonstrated a statistically significant difference in body fat (BF) (29.6 ± 6.3 to 27.6 ± 5.3, p= 0.002) and BMI (29.6 ± 6.6 to 28.9 ± 6.34, p=0.005) from pre-test to post-test. Uhorchak et al reported on 8 female ACL tears and found that 1 SD above the mean for BMI, measured at the entry physical examination for the military academy, was a risk factor for ACL tears in military cadets (Trojian & Collins, 2006; Uhorchak et al., 2003). In their study, it was suggested that BMI might be a surrogate marker for fitness, or some other factor in female military cadets. This finding provides additional support for the use of the training protocol to prevent ACL injury through general fitness improvement.

This study has potential limitations. The participants were selected based upon convenience of practice times and class times and delegated to intervention group based on ability to participate in the training. The resistance training control group consisted of those AAF who were unable to schedule the training. However, despite these limitations, the results of this study provide data that suggests a neuromuscular training program that combines several components, including injury-prevention techniques can decrease the potential biomechanical risk factors of lower-extremity injury in AAF athletes. ACL injury has various risk factors such as, biomechanical and neuromuscular risk profiles (Hewett et al., 2017). There is a need to address proximal risk factors, including the trunk and hip, that involve in lower extremity movement biomechanics that result in ACL injuries. Further research should include incorporating neuromuscular training within yearly planned periodization training programs.

Although no direct evidence exhibits that neuromuscular training improves win-loss records, scientific evidence shows that increased performance relates to level of play in diverse divisions (National Collegiate Athletic Association Division I, II, III) (Myer et al., 2005). The present findings confirm that AAF athletes who train with a comprehensive neuromuscular training program could potentially decrease injury risk and likely enhance their productivity across their sport season. This aspect of the research suggested that off-season and/or pre-season strength and conditioning programs should include components of plyometrics and movement training, resistance training, core strengthening and balance training. These components may be combinatory and cumulative benefits in their effects of improving lower-extremity biomechanics and increasing performance in AAF athlete.

References

Agel, J., Rockwood, T., & Klossner, D. (2016). Collegiate ACL Injury Rates Across 15 Sports: National Collegiate Athletic Association Injury Surveillance System Data Update (2004-2005 Through 2012-2013). *Clin J Sport Med*, **26(6)**, 518-523. doi: 10.1097/JSM.0000000000000290

Boden, B. P., Dean, G. S., Feagin, J. A., Jr., & Garrett, W. E., Jr. (2000). Mechanisms of anterior cruciate ligament injury. *Orthopedics*, **23(6)**, 573-578.

Caraffa, A., Cerulli, G., Projetti, M., Aisa, G., & Rizzo, A. (1996). Prevention of anterior cruciate ligament injuries in soccer. A prospective controlled study of proprioceptive training. *Knee Surg Sports Traumatol Arthrosc*, **4(1)**, 19-21. doi: 10.1007/BF01565992

Ford, K. R., Myer, G. D., & Hewett, T. E. (2003). Valgus knee motion during landing in high school female and male basketball players. *Med Sci Sports Exerc*, **35(10)**, 1745-1750. doi: 10.1249/01.MSS.0000089346.85744.D9

Griffin, L. Y., Agel, J., Albohm, M. J., Arendt, E. A., Dick, R. W., Garrett, W. E., . . . Wojtys, E. M. (2000). Noncontact anterior cruciate ligament injuries: risk factors and prevention strategies. *J Am Acad Orthop Surg*, **8(3)**, 141-150. doi: 10.5435/00124635-200005000-00001

Heidt, R. S., Jr., Sweeterman, L. M., Carlonas, R. L., Traub, J. A., & Tekulve, F. X. (2000). Avoidance of soccer injuries with preseason conditioning. *Am J Sports Med*, **28(5)**, 659-662. doi: 10.1177/03635465000280050601

Hewett, T. E., Ford, K. R., Hoogenboom, B. J., & Myer, G. D. (2010). Understanding and preventing acl injuries: current biomechanical and epidemiologic considerations - update 2010. *N Am J Sports Phys Ther*, **5(4)**, 234-251.

Hewett, T. E., Ford, K. R., Xu, Y. Y., Khoury, J., & Myer, G. D. (2017). Effectiveness of Neuromuscular Training Based on the Neuromuscular Risk Profile. *Am J Sports Med*, **45(9)**, 2142-2147. doi: 10.1177/0363546517700128

Hewett, T. E., Lindenfeld, T. N., Riccobene, J. V., & Noyes, F. R. (1999). The effect of neuromuscular training on the incidence of knee injury in female athletes. A prospective study. *Am J Sports Med*, **27(6)**, 699-706. doi: 10.1177/03635465990270060301

Hewett, T. E., Myer, G. D., & Ford, K. R. (2004). Decrease in neuromuscular control about the knee with maturation in female athletes. *J Bone Joint Surg Am*, **86(8)**, 1601-1608. doi: 10.2106/00004623-200408000-00001

Hewett, T. E., Myer, G. D., Ford, K. R., Heidt, R. S., Jr., Colosimo, A. J., McLean, S. G., . . . Succop, P. (2005). Biomechanical measures of neuromuscular control and valgus loading of the knee predict anterior cruciate ligament injury risk in female athletes: a prospective study. *Am J Sports Med*, **33(4)**, 492-501. doi: 10.1177/0363546504269591

Hewett, T. E., Stroupe, A. L., Nance, T. A., & Noyes, F. R. (1996). Plyometric training in female athletes. Decreased impact forces and increased hamstring torques. *Am J Sports Med*, **24(6)**, 765-773. doi: 10.1177/036354659602400611

Hughley, T. W., Ford, K. R., Myer, G. D., Johnson, J., & Yoon, A. (2019). Comparison of knee valgus motion in African American male and female collegiate athletes. *International Journal of Applied Sports Sciences*, **31(1)**, 43-51.

Kawaguchi, K., Taketomi, S., Mizutani, Y., Uchiyama, E., Ikegami, Y., Tanaka, S., . . . Nakamura, Y. (2021). Sex-Based Differences in the Drop Vertical Jump as Revealed by Video Motion Capture Analysis Using Artificial Intelligence. *Orthop J Sports Med*, **9(11)**, 23259671211048188. doi: 10.1177/23259671211048188

Kovacs, E. J., Birmingham, T. B., Forwell, L., & Litchfield, R. B. (2004). Effect of training on postural control in figure skaters: a randomized controlled trial of neuromuscular versus basic off-ice training programs. *Clin J Sport Med*, **14(4)**, 215-224. doi: 10.1097/00042752-200407000-00004

Kraemer, W. J., Duncan, N. D., & Volek, J. S. (1998). Resistance training and elite athletes: adaptations and program considerations. *J Orthop Sports Phys Ther*, **28(2)**, 110-119. doi: 10.2519/jospt.1998.28.2.110

LaBella, C. R., Huxford, M. R., Grissom, J., Kim, K. Y., Peng, J., & Christoffel, K. K. (2011). Effect of neuromuscular warm-up on injuries in female soccer and basketball athletes in urban public high schools: cluster randomized controlled trial. *Arch Pediatr Adolesc Med*, **165(11)**, 1033-1040. doi: 10.1001/archpediatrics.2011.168

Lephart, S. M., Abt, J. P., Ferris, C. M., Sell, T. C., Nagai, T., Myers, J. B., & Irrgang, J. J. (2005). Neuromuscular and biomechanical characteristic changes in high school athletes: a plyometric versus basic resistance program. *Br J Sports Med*, **39(12)**, 932-938. doi: 10.1136/bjsm.2005.019083

Levins, J. G., Argentieri, E. C., Sturnick, D. R., Gardner-Morse, M., Vacek, P. M., Tourville, T. W., . . . Beynnon, B. D. (2017). Geometric Characteristics of the Knee Are Associated With a Noncontact ACL Injury to the Contralateral Knee After Unilateral ACL Injury in Young Female Athletes. *Am J Sports Med*, **45(14)**, 3223-3232. doi: 10.1177/0363546517735091

Mandelbaum, B. R., Silvers, H. J., Watanabe, D. S., Knarr, J. F., Thomas, S. D., Griffin, L. Y., . . . Garrett, W., Jr. (2005). Effectiveness of a neuromuscular and proprioceptive training program in preventing anterior cruciate ligament injuries in female athletes: 2-year follow-up. *Am J Sports Med*, **33(7)**, 1003-1010. doi: 10.1177/0363546504272261

Myer, G. D., Chu, D. A., Brent, J. L., & Hewett, T. E. (2008). Trunk and hip control neuromuscular training for the prevention of knee joint injury. *Clin Sports Med*, **27(3)**, 425-448, ix. doi: 10.1016/j.csm.2008.02.006

Myer, G. D., Ford, K. R., & Hewett, T. E. (2011). New method to identify athletes at high risk of ACL injury using clinic-based measurements and freeware computer analysis. *Br J Sports Med*, **45(4)**, 238-244. doi: 10.1136/bjsm.2010.072843

Myer, G. D., Ford, K. R., Palumbo, J. P., & Hewett, T. E. (2005). Neuromuscular training improves performance and lower-extremity biomechanics in female athletes. *J Strength Cond Res*, **19(1)**, 51-60. doi: 10.1519/13643.1

Myklebust, G., Engebretsen, L., Braekken, I. H., Skjolberg, A., Olsen, O. E., & Bahr, R. (2003). Prevention of anterior cruciate ligament injuries in female team handball players: a prospective intervention study over three seasons. *Clin J Sport Med*, **13(2)**, 71-78. doi: 10.1097/00042752-200303000-00002

Nedergaard, N. J., Dalbo, S., Petersen, S. V., Zebis, M. K., & Bencke, J. (2020). Biomechanical and neuromuscular comparison of single- and multi-planar jump tests and a side-cutting maneuver: Implications for ACL injury risk assessment. *Knee*, **27(2)**, 324-333. doi: 10.1016/j.knee.2019.10.022

Nessler, T., Denney, L., & Sampley, J. (2017). ACL Injury Prevention: What Does Research Tell Us? *Curr Rev Musculoskelet Med*, **10(3)**, 281-288. doi: 10.1007/s12178-017-9416-5

Petushek, E. J., Sugimoto, D., Stoolmiller, M., Smith, G., & Myer, G. D. (2019). Evidence-Based Best-Practice Guidelines for Preventing Anterior Cruciate Ligament Injuries in Young Female Athletes: A Systematic Review and Meta-analysis. *Am J Sports Med*, **47(7)**, 1744-1753. doi: 10.1177/0363546518782460

Scarborough, D. M., Linderman, S. E., Cohen, V. A., Berkson, E. M., Eckert, M. M., & Oh, L. S. (2019). Neuromuscular Control of Vertical Jumps in Female Adolescents. *Sports Health*, **11(4)**, 343-349. doi: 10.1177/1941738119846513

Shelbourne, K. D., Gray, T., & Benner, R. W. (2007). Intercondylar notch width measurement differences between African American and white men and women with intact anterior cruciate ligament knees. *Am J Sports Med*, **35(8)**, 1304-1307. doi: 10.1177/0363546507300060

Trojian, T. H., & Collins, S. (2006). The anterior cruciate ligament tear rate varies by race in professional Women's basketball. *Am J Sports Med*, **34(6)**, 895-898. doi: 10.1177/0363546505284384

Uhorchak, J. M., Scoville, C. R., Williams, G. N., Arciero, R. A., St Pierre, P., & Taylor, D. C. (2003). Risk factors associated with noncontact injury of the anterior cruciate ligament: a prospective four-year evaluation of 859 West Point cadets. *Am J Sports Med*, **31(6)**, 831-842. doi: 10.1177/03635465030310061801