IJSPT

ORIGINAL RESEARCH

DETERMINATION OF CLINICALLY RELEVANT DIFFERENCES IN FRONTAL PLANE HOP TESTS IN WOMEN'S COLLEGIATE BASKETBALL AND SOCCER PLAYERS

Kelly Hardesty[1]
Eric J. Hegedus, PT, DPT, OCS, CSCS[2]
Kevin R. Ford, PhD[2]
Anh-Dung Nguyen, PhD, ATC[3]
Jeffrey B. Taylor, PT, PhD, DPT, OCS, SCS, CSCS[2]

ABSTRACT

Background: ACL injury prevention programs are less successful in female basketball players than in soccer players. Previous authors have identified anthropometric and biomechanical differences between the athletes and different sport-specific demands, including a higher frequency of frontal plane activities in basketball. Current injury risk screening and preventive training practices do not place a strong emphasis on frontal plane activities. The medial and lateral triple hop for distance tests may be beneficial for use in the basketball population.

Hypothesis/Purpose: To 1) establish normative values for the medial and lateral triple hop tests in healthy female collegiate athletes, and 2) analyze differences in test scores between female basketball and soccer players. It was hypothesized that due to the frequent frontal plane demands of their sport, basketball players would exhibit greater performance during these frontal plane performance tests.

Study Design: Cross-sectional.

Methods: Thirty-two NCAA Division-1 female athletes (20 soccer, 12 basketball) performed three trials each of a medial and lateral triple hop for distance test. Distances were normalized to height and mass in order to account for anthropometric differences. Repeated measures ANOVAs were performed to identify statistically significant main effects of sport (basketball vs. soccer), and side (right vs. left), and sport x side interactions.

Results: After accounting for anthropometric differences, soccer players exhibited significantly better performance than basketball players in the medial and lateral triple hop tests ($p < 0.05$). Significant side differences ($p = 0.02$) were identified in the entire population for the medial triple hop test, such that participants jumped farther on their left (400.3 ± 41.5 cm) than right (387.9 ± 43.4 cm) limbs, but no side differences were identified in the lateral triple hop. No significant side x sport interactions were identified.

Conclusions: Women's basketball players exhibit decreased performance of frontal plane hop tests when compared to women's soccer players. Additionally, the medial triple hop for distance test may be effective at identifying side-to-side asymmetries

Level of Evidence: 3

Key words: Basketball, frontal plane, hop testing, performance tests, screening, soccer

[1] Department of Exercise Science, High Point University, High Point, NC, USA
[2] Department of Physical Therapy, High Point University, High Point, NC, USA
[3] Department of Athletic Training, High Point University, High Point, NC, USA

CORRESPONDING AUTHOR
Jeffrey B. Taylor PT, PhD, DPT, OCS, SCS, CSCS
One University Parkway, High Point, NC, USA 27268
Phone: 336-841-9492
E-mail: jtaylor@highpoint.edu

INTRODUCTION

Multidirectional women's sports, including basketball and soccer, have relatively high anterior cruciate ligament (ACL) injury incidence rates.[1] With these elevated risks, ACL injury prevention programs have been designed to decrease the risk of injury and subsequent long-term ramifications (e.g. financial costs, increased risk of osteoarthritis) associated with an ACL rupture.[2,3] Most prevention programs encompass some combination of strength, agility, and plyometric training to improve lower extremity biomechanics during high-risk sport related activities like jumping and cutting.[4] However, the effectiveness of these programs is different between the sports, as women's soccer players have shown a higher reduction of injury risk compared to women's basketball players.[5,6] The reason for the lack of effectiveness for injury prevention programs in women's basketball is unknown.

One reason for the decreased effectiveness of prevention programs in basketball may be because women's basketball and soccer players differ anthropometrically, and employ different biomechanical movement strategies during sport-specific tasks. Women's basketball players are taller, heavier, have greater lean body mass, and possess a higher body fat percentage compared to women's soccer players.[7-9] Biomechanically, basketball players jump and land with larger ground reaction forces, while soccer players display higher ground reaction forces during cutting tasks.[10] While jumping, landing, and cutting with higher ground reaction forces may increase explosiveness and performance, this strategy may also place these two different groups of female athletes at a relatively higher risk of injury during their respective tasks. Support for this contention is found in that 60% of ACL injuries in basketball occur during a jump landing, whereas the majority of soccer injuries are the result of a cutting mechanism.[11-14]

Another reason that ACL injury prevention programs may have differing success in women's basketball and soccer players may be related to the distinctly different demands of the two sports. Basketball players jump vertically and move medially and laterally to a greater extent than soccer players while soccer players cover more ground horizontally while cutting and running in a straight line.[15-18] Current prevention programs lack emphasis on medial and lateral demands, consequently making them more specific to the demands of soccer, and potentially more successful in soccer than basketball players.

Similarly, conventional physical performance tests, such as the drop vertical jump, triple hop for distance, broad jump, and timed 6M hop test are commonly used to help identify those that may be at risk for injury and a good candidate for preventative training by assessing landing biomechanics or side-to-side asymmetries,[19] yet these standard tests are predominantly based in the sagittal plane and do not analyze an athlete's ability to move in other planes. Compared to sagittal plane movements, frontal plane movements elicit distinct lower extremity kinematics and kinetics.[20] Frequent movement in the frontal plane may alter performance and/or injury risk and warrant screening tests that emphasize frontal plane demands to complement standard sagittal plane tests.

The frontal plane-focused medial and lateral triple hop for distance tests are relatively new tests that may help to identify deficits in frontal plane movements to help explain differences between basketball and soccer players; however, these modified single leg performance tests have only been assessed in dancers with hip pathology.[21] Thus, the purpose of this paper was to 1) establish normative values for the medial and lateral triple hop for distance tests in healthy female collegiate athletes, and 2) analyze differences in test scores between female basketball and soccer players. It was hypothesized that due to the frequent frontal plane demands of their sport, basketball players would exhibit greater performance during these frontal plane performance tests.

METHODS

Subjects

Thirty-two NCAA Division-I female athletes (20 soccer, 12 basketball) participated in this study. All participants exclusively participated in either basketball or soccer at the collegiate level. Participants were excluded if they were not medically cleared for full sport participation. Informed written consent, approved by the High Point University Institutional Review Board was obtained prior to testing.

Procedures

Testing occurred as part of a larger pre-season injury risk factor screening session. The medial and lateral triple hop for distance tests were performed as previously described by Kivlan et al.,[21] by measuring the distance traveled over continuous, consecutive single-leg medial or lateral hops. A standard cloth tape measure was affixed to a rubber floor in a biomechanics laboratory setting. Participants started on a single limb, perpendicular to the start of the tape measure with their upper extremities and uninvolved lower limb in a self-selected position. For the lateral triple hop, participants were instructed to hop laterally (with respect to their weight-bearing limb), with measurements taken from the lateral surface of the shoe. The medial triple hop test was conducted in the same manner as the lateral hop test but in the medial direction of the stance leg. In accordance with previous studies and to ensure the most natural movement pattern, there was no standardization of upper extremity or uninvolved lower extremity position during the test.[21] Participants were required to control their final landing, keeping their toes pointing straight forward, parallel to the starting line, throughout the duration of the hopping trial. Both direction and limb were randomized across all participants for each trial. Each participant was given one practice trial on each limb, in each direction prior to measurement. Three trials of each limb in each direction were then completed, with all three trials averaged and normalized to 1) height, 2) mass, and 3) height and mass, because of the considerable anthropometric differences between the two sets of athletes. Limb dominance was not assessed because of the varying definitions of dominance in the soccer (based on kicking limb) and basketball (based on jumping limb).

Data Analysis

SPSS (Version 23, IBM Corp, Armonk, New York, USA) was used for statistical analyses. Independent t-tests compared differences in anthropometrics (age, height, mass, BMI) between basketball and soccer players. Separate repeated measures ANOVAs were then performed to identify statistically significant main effects of sport (basketball vs. soccer), and side (right vs. left), and sport x side interactions for raw distances, and distances normalized to height and mass for medial and lateral triple hop scores. When necessary, post-hoc independent t-tests were used to further test pairwise comparisons. Statistical significance was set *a priori* at $\alpha < 0.05$ for all analyses.

RESULTS

Anthropometric data are reported by sport in Table 1. Statistically significant differences were identified, where height ($p = 0.02$), mass ($p = 0.004$), and body mass index (BMI) ($p = 0.02$) were greater in collegiate basketball compared to soccer players. Descriptive statistics of medial and lateral triple hop for distance measurements are reported in Table 2. There were no significant differences between sports when analyzing raw medial ($p = 0.11$) or lateral ($p = 0.20$) triple hop distances, yet after distances were normalized to height, soccer players jumped significantly further than basketball players in the medial ($p = 0.01$) and lateral ($p = 0.04$) directions. Similarly, when accounting for mass, soccer players jumped further than basketball players, with significant differences in the medial ($p = 0.001$) and lateral ($p = 0.003$) directions. Normalizing to both height and mass led to consistent significant differences in medial ($p = 0.001$) and lateral ($p = 0.001$) directions.

Additionally, statistically significant side differences ($p = 0.02$) were identified in the entire population for the medial triple hop, such that participants jumped farther on their left (400.3 ± 41.5 cm) than right (387.9 ± 43.4 cm) limbs, but no side differences were identified in the lateral triple hop ($p = 0.65$). Further, no significant side x sport interactions were identified.

DISCUSSION

Past research has indicated that ACL injury prevention programs are less successful in women's

Table 1. *Demographic and anthropometric measures of population*

	Basketball (n=12)	Soccer (n=20)
Age (years)	20.0 ± 1.4	19.2 ± 1.0
Height (m)*	*1.73 ± 0.07*	*1.67 ± 0.06*
Mass (kg)*	*80.2 ± 13.6*	*65.9 ± 6.6*
BMI (kg/m^2)*	*26.7 ± 3.6*	*23.6 ± 2.2*

*significant difference between basketball and soccer players

Table 2. *Mean medial (MTH) and lateral (LTH) triple hop for distance scores in collegiate female basketball and soccer players*

	Total (n=32)		Soccer (n=20)		Basketball (n=12)	
	Left	Right	Left	Right	Left	Right
MTH Raw Distance (cm)†	400.3 ± 41.6	387.9 ± 43.4	407.5 ± 44.3	398.2 ± 35.7	388.3 ± 35.0	370.8 ± 50.8
MTH (normalized to height)*†	2.36 ± 0.24	2.29 ± 0.26	2.44 ± 0.23	2.38 ± 0.17	2.25 ± 0.21	2.15 ± 0.32
MTH (normalized to mass)*†	5.77 ± 1.15	5.60 ± 1.16	6.24 ± 0.90	6.08 ± 0.68	5.00 ± 1.13	4.80 ± 1.37
MTH (normalized to height and mass)*†	0.034 ± 0.007	0.033 ± 0.007	0.037 ± 0.005	0.036 ± 0.004	0.029 ± 0.007	0.028 ± 0.009
LTH Raw Distance (cm)	363.4 ± 41.5	361.0 ± 47.3	369.3 ± 42.1	369.8 ± 41.1	353.6 ± 40.5	346.2 ± 54.9
LTH (normalized to height)*	2.15 ± 0.25	2.13 ± 0.28	2.21 ± 0.23	2.21 ± 0.22	2.05 ± 0.26	2.00 ± 0.33
LTH (normalized to mass)*	5.24 ± 1.04	5.21 ± 1.10	5.63 ± 0.68	5.64 ± 0.72	4.58 ± 1.24	4.49 ± 1.28
LTH (normalized to height and mass)*	0.031 ± 0.007	0.031 ± 0.007	0.034 ± 0.004	0.034 ± 0.004	0.027 ± 0.008	0.027 ± 0.008

** significant differences between basketball and soccer players ($p<0.05$), † significant side to side differences in all cohorts ($p<0.05$)*

basketball compared to soccer,[5,6] yet the reason for this discrepancy is unclear. Identifying anatomical, neuromuscular, biomechanical and functional differences between athletes of the two sports may help clinicians design future prevention programs to target specific risk factors for each sport. Results of this study indicate that basketball and soccer players perform similarly in the medial and lateral triple hop for distance tests. However, after accounting for anthropometric differences between the two sets of

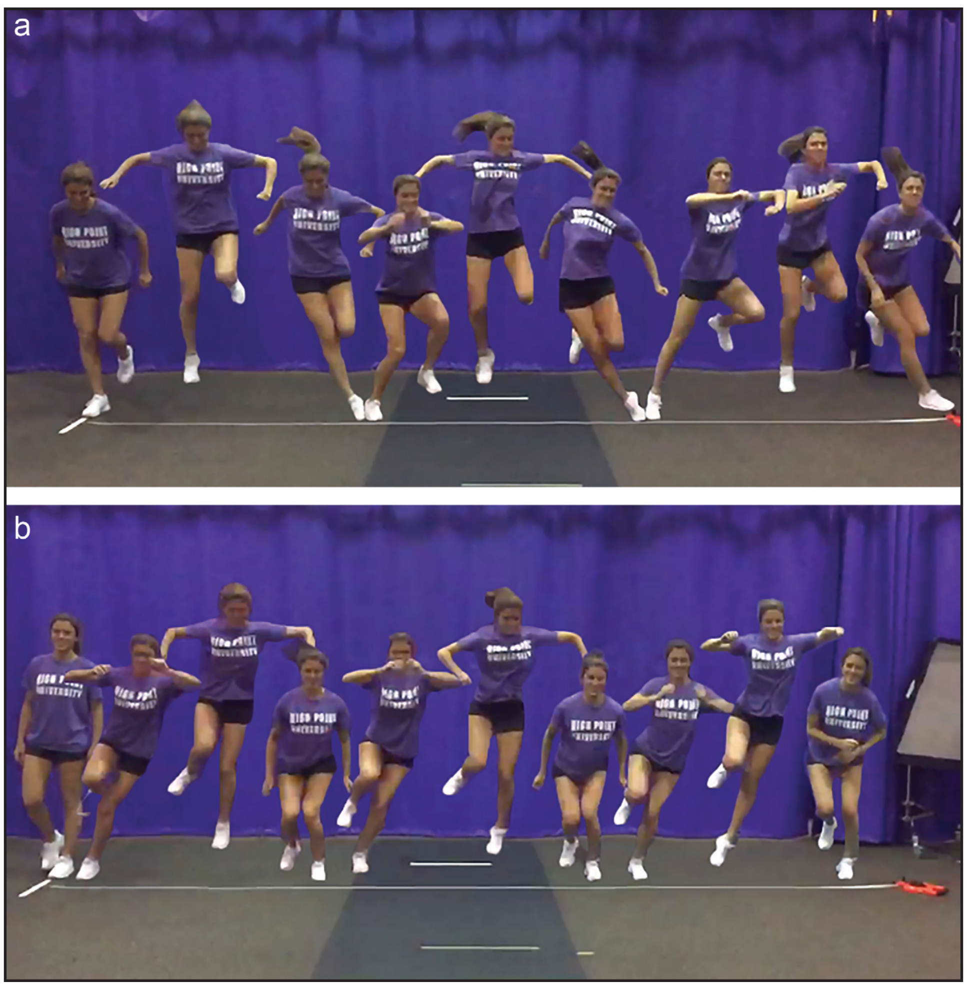

Figure 1. *Participant performing the a) medial and b) lateral triple hop for distance tests.*

athletes, basketball players are unable to jump as far in the frontal plane as soccer players. These weaknesses may translate to less lower extremity control during medial and lateral movements, potentially putting basketball players at higher risk for injury, considering the frequency of such movements in their sport.

Results from both the medial and lateral triple hop for distance tests indicate that relative to body size, soccer players are more powerful in the frontal plane than basketball players. These findings do not support the original hypothesis that basketball players would hop greater distances compared to soccer players. This was based on the specificity of training principle, where basketball players jump and move more often in the frontal plane than soccer players,[16, 18] and therefore, would have adapted to become more powerful in that plane. One possible explanation for the current findings may relate to anthropometric differences between the athletes. Basketball players possess larger BMIs than soccer players and show a significantly larger increase in total body and fat mass over their collegiate careers than soccer players.[7] Because basketball players are taller and heavier, they may not have developed the strength to biomechanically maneuver the long lever arms associated with their height, nor adequate strength to effectively move their body mass outside of the sagittal plane. This is consistent with literature that indicates that despite demands of the game, basketball players exhibit lower jump heights and less explosive jumping patterns than athletes of other sports.[22]

However, previous research has found no significant differences between female basketball and soccer players in raw forward triple hop distances and higher raw distances in male basketball than soccer players.[23] This finding may be because the medial and lateral triple hop for distance tests measure different constructs than the forward triple hop for distance test. For example, the forward triple hop for distance test has been closely linked with both quadriceps and hamstrings strength,[24] yet past evidence suggests that basketball and soccer players do not exhibit differences in sagittal plane thigh strength.[25] Similar data linking the medial and lateral hop tests to the strength of certain muscles is limited. In fact, Kea et al[26] found little correlation between single medial and lateral hop tests and isokinetic testing of the hip abductors and adductors. This finding can again be attributed to isokinetic strength and frontal plane hopping being different constructs or that hip abductor/adductor strength is not the sole factor influencing frontal plane movement performance. In other words, an athlete may simply be able to change the position of the stance leg to recruit the larger, more powerful gluteus maximus rather than the gluteus medius.[27] This strategy would be controlled in the current study's method of testing but may explain why it should not be assumed that basketball players would fare better on frontal plane hop tests. There is some support that simply lowering the center of gravity (i.e. greater hip and knee flexion) may be an even more important component of effective lateral movement.[27, 28] Further understanding of the specific constructs tested in medial and lateral triple hop for distance tests is needed.

The results that basketball players exhibit less powerful movement potential in the frontal plane may have direct clinical implications. While sport-specificity is generally a strong component of rehabilitation and return to play practices,[29] it is less common in the injury prevention paradigm, despite different effectiveness of prevention programs in various sports.[5, 6] The results suggest that injury prevention programs, specifically in women's basketball players, may need to place a stronger emphasis on frontal plane activities than current programs administer. In reviewing the three ACL injury prevention programs that have been studied in women's basketball players,[30-32] only 12% of plyometric activities are devoted to frontal plane movements. Though the specific prescription of plyometric exercises need more study, activities such as lateral bounding on flat or plyometric boxes, or perhaps even frontal plane triple hops with or without a vertical component should begin to be incorporated into prevention practices. Because most injury prevention programs emphasize sagittal plane movements, they may not be providing adequate stimulus to improve biomechanics and performance during frontal plane movements, which appear to be inherently weaker in basketball players.

Frontal plane hop tests may also have merit in more general rehabilitation or injury prevention settings.

The medial and lateral triple hop tests used in this study have been previously examined in dancers with hip pathology, with the medial triple hop test being able to identify side-to-side differences between the involved and uninvolved sides. Another frontal plane test gaining traction in the literature is the lateral leap and catch, which assesses power (speed of movement) in addition to movement quality.[33] To date, none of the frontal plane hop tests have been validated for prediction of injury risk or successful return to play. Continuing to develop and assess frontal plane testing is necessary for athletes with high frontal plane demands inherent within their sport. This study provides normative values for the medial and lateral triple hop for distance tests in healthy collegiate athletes. These results can be used by clinicians as a complementary piece of information to other tests and measures to help gauge frontal plane performance during their assessment of high-level athletes. However, clinicians must make appropriate clinical decisions as to whether their patients/athletes are able to safely perform this high-level task.

The results of the current study indicate that the medial triple hop test elicited side-to-side differences, such that athlete's performed better on their left limb than their right limb. The authors purposefully chose not to categorize limbs based on dominance in this study. While limb dominance may be intuitively easy to define in soccer by the preferred kicking limb, this definition is not applicable to basketball players. While jumping may be a more appropriate activity to define dominance in basketball players, a player's self-selected dominant jumping limb is not consistent with their vertical or horizontal jumping performance.[34] However, the fact that participants in this study showed greater performance on their left than right limbs may be related to sport-specific demands, as a large majority of soccer players preferred to kick with their right limbs (making the left their preferred stance limb) and all basketball players were right-handed, generally making the left limb the preferred jumping and landing limb during single-leg activities. Further exploration of differences in limb dominance in these two sports may provide additional insight to the difference in effectiveness of ACL injury prevention programs.

Results of this study indicate that further research may be needed to 1) establish the clinical utility of frontal plane hop tests in an athletic or clinical setting and 2) further understand differences between basketball and soccer players. Future studies could identify whether frontal plane hop tests have the ability to complement other tests and measures as potential predictors of injury, rehabilitation progression or successful return to play in healthy or clinical populations, or whether these tests provide similar information previously established hop batteries.

Additionally, while this study identified significant differences in medial and lateral triple hop for distance tests between collegiate female basketball and soccer players, forward triple hop for distance tests were not performed in both groups. Confirming previous findings that there are no significant differences in this same population of women's basketball and soccer players in the sagittal plane would have provided even further confirmation that these differences identified in the frontal plane are clinically important, and may lead to further study regarding other biomechanical or neuromuscular differences that exist between athletes that participate in these sports.

CONCLUSION

Women's basketball players exhibit decreased performance of frontal plane hop tests as compared to women's soccer players. Considering the high rate of ACL injuries, the relatively poor efficacy of ACL injury prevention programs and the frequent frontal plane demands of the sport, basketball players may benefit from further emphasis on frontal plane screening measures, strength and neuromuscular control training.

REFERENCES

1. Hootman JM, Dick R, Agel J. Epidemiology of collegiate injuries for 15 sports: summary and recommendations for injury prevention initiatives. *J Athl Train*. 2007;42:311-319.
2. Mather RC, Koenig L, Kocher MS, et al. Societal and economic impact of anterior cruciate ligament tears. *J Bone Joint Surg Am*. 2013;95:1751-1759.
3. Øiestad BE, Engebretsen L, Storheim K, et al. Knee osteoarthritis after anterior cruciate ligament injury: a systematic review. *Am J Sports Med*. 2009;37:1434-1443.

4. Taylor JB, Waxman JP, Richter SJ, et al. Evaluation of the effectiveness of anterior cruciate ligament injury prevention programme training components: a systematic review and meta-analysis. *Br J Sports Med*. 2015;49:79-87.
5. Michaelidis M, Koumantakis GA. Effects of knee injury primary prevention programs on anterior cruciate ligament injury rates in female athletes in different sports: a systematic review. *Phys Ther Sport*. 2014;15:200-210.
6. Prodromos CC, Han Y, Rogowski J, et al. A meta-analysis of the incidence of anterior cruciate ligament tears as a function of gender, sport, and a knee injury-reduction regimen. *Arthroscopy*. 2007;23:1320-1325 e1326.
7. Stanforth PR, Crim BN, Stanforth D, et al. Body composition changes among female NCAA Division 1 athletes across the competitive season and over a multi-year time frame. *J Strength Cond Res*. 2013;28:300-307.
8. Munro A, Herrington L, Comfort P. Comparison of landing knee valgus angle between female basketball and football athletes: possible implications for anterior cruciate ligament and patellofemoral joint injury rates. *Phys Ther Sport*. 2012;13:259-264.
9. Zakas A, Mandroukas K, Vamvakoudis E, et al. Peak torque of quadriceps and hamstring muscles in basketball and soccer players of different divisions. *J Sports Med Phys Fitness*. 1995;35:199-205.
10. Cowley HR, Ford KR, Myer GD, et al. Differences in neuromuscular strategies between landing and cutting tasks in female basketball and soccer athletes. *J Athl Train*. 2006;41:67-73.
11. Boden BP, Torg JS, Knowles SB, et al. Video analysis of anterior cruciate ligament injury: abnormalities in hip and ankle kinematics. *Am J Sports Med*. 2009;37:252-259.
12. Krosshaug T, Nakamae A, Boden BP, et al. Mechanisms of anterior cruciate ligament injury in basketball: video analysis of 39 cases. *Am J Sports Med*. 2007;35:359-367.
13. Piasecki DP, Spindler KP, Warren TA, et al. Intraarticular injuries associated with anterior cruciate ligament tear: findings at ligament reconstruction in high school and recreational athletes. An analysis of sex-based differences. *Am J Sports Med*. 2003;31:601-605.
14. Faude O, Junge A, Kindermann W, et al. Injuries in female soccer players: a prospective study in the German national league. *Am J Sports Med*. 2005;33:1694-1700.
15. Ben Abdelkrim N, El Fazaa S, El Ati J. Time-motion analysis and physiological data of elite under-19-year-old basketball players during competition. *Br J Sports Med*. 2007;41:69-75; discussion 75.
16. Matthew D, Delextrat A. Heart rate, blood lactate concentration, and time-motion analysis of female basketball players during competition. *J Sports Sci*. 2009;27:813-821.
17. Nedelec M, McCall A, Carling C, et al. The influence of soccer playing actions on the recovery kinetics after a soccer match. *J Strength Cond Res*. 2014;28:1517-1523.
18. Bloomfield J, Polman R, O'Donoghue P. Physical Demands of Different Positions in FA Premier League Soccer. *J Sports Sci Med*. 2007;6:63-70.
19. Hegedus EJ, McDonough S, Bleakley C, et al. Clinician-friendly lower extremity physical performance measures in athletes: a systematic review of measurement properties and correlation with injury, part 1. The tests for knee function including the hop tests. *Br J Sports Med*. 2015;49:642-648.
20. Taylor JB, Ford KR, Nguyen AD, et al. Biomechanical Comparison of Single- and Double-Leg Jump Landings in the Sagittal and Frontal Plane. *Orthop J Sports Med*. 2016;4:2325967116655158.
21. Kivlan BR, Carcia CR, Clemente FR, et al. Reliability and validity of functional performance tests in dancers with hip dysfunction. *Int J Sports Phys Ther*. 2013;8:360-369.
22. Laffaye G, Phillip W, Tom T. Countermovement Jump Height: Gender and Sport-Specific Differences in the Force-Time Variables. *J Strength Cond Res*. 2013;
23. Myers BA, Jenkins WL, Killian C, et al. Normative data for hop tests in high school and collegiate basketball and soccer players. *Int J Sports Phys Ther*. 2014;9:596-603.
24. Hamilton RT, Shultz SJ, Schmitz RJ, et al. Triple-hop distance as a valid predictor of lower limb strength and power. *J Athl Train*. 2008;43:144-151.
25. Rosene JM, Fogarty TD, Mahaffey BL. Isokinetic Hamstrings:Quadriceps Ratios in Intercollegiate Athletes. *J Athl Train*. 2001;36:378-383.
26. Kea J, Kramer J, Forwell L, et al. Hip abduction-adduction strength and one-leg hop tests: test-retest reliability and relationship to function in elite ice hockey players. *J Orthop Sports Phys Ther*. 2001;31:446-455.
27. Shimokochi Y, Ide D, Kokubu M, et al. Relationships among performance of lateral cutting maneuver from lateral sliding and hip extension and abduction motions, ground reaction force, and body center of mass height. *J Strength Cond Res*. 2013;27:1851-1860.

28. Sasaki S, Koga H, Krosshaug T, et al. Biomechanical Analysis of Defensive Cutting Actions During Game Situations: Six Cases in Collegiate Soccer Competitions. *J Hum Kinet*. 2015;46:9-18.
29. Waters E. Suggestions from the field for return to sports participation following anterior cruciate ligament reconstruction: basketball. *J Orthop Sports Phys Ther*. 2012;42:326-336.
30. LaBella CR, Huxford MR, Grissom J, et al. 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*. 2011;165:1033-1040.
31. Pfeiffer RP, Shea KG, Roberts D, et al. Lack of effect of a knee ligament injury prevention program on the incidence of noncontact anterior cruciate ligament injury. *J Bone Joint Surg Am*. 2006;88:1769-1774.
32. Hewett TE, Lindenfeld TN, Riccobene JV, et al. The effect of neuromuscular training on the incidence of knee injury in female athletes. A prospective study. *Am J Sports Med*. 1999;27:699-706.
33. Haitz K, Shultz R, Hodgins M, et al. Test-retest and interrater reliability of the functional lower extremity evaluation. *J Orthop Sports Phys Ther*. 2014;44:947-954.
34. Mulrey C, Ford KR, Shultz SJ, et al. Identifying Limb Dominance in Adolescent Female Basketball Players: Implications for Biomechanical Research: 2654 Board #177 June 3, 11: 00 AM - 12: 30 PM. *Med Sci Sports Exerc*. 2016;48:741.