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The Effects of Functional Fatigue on Ground Reaction Forces of a Jump, Land, and Cut Task

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Abstract**-**Rapid acceleration, deceleration, landing and change of direction have been implicated as mechanisms of noncontact anterior cruciate ligament (ACL) injury. PURPOSE: To examine the ground reaction forces occurring to the knee during non-fatigued and fatigued jump, land and cut maneuvers in three unplanned cutting directions. METHODS: Eleven healthy, adult female collegiate soccer athletes participated in this study (age= 20.3±0.9 years; height= 167.4±4.8 cm; mass= 63.7±7.7 kg). Each subject was instructed to perform 9 jump, land, and cut maneuvers in a pre-fatigued state and fatigued state. The protocols were randomly assigned to include 3 cuts in each of the three directions. The functional fatigue protocol consisted of rapid acceleration, deceleration, and change of direction activities. A 2x2 ANOVA design was used to compare groups (fatigue state) and (leg dominance). RESULTS: Differences were noted in the medial direction during the left cut land (p=0.049). Differences in the anterior-posterior forces occurred during fatigued landing tasks for all three cutting directions (left, p=0.049; center, p=0.000; right, p=0.009), and for the center cut push off (p=0.020). Fatigue appeared to have a significant impact on the vertical push off of all three directions (left, p=0.023; center, p=0.000; right, p=0.047). CONCLUSION: Fatigue has an important impact on jump, land and cut maneuvers regardless of cutting direction. Fatigue was noted to impact the anterior-posterior direction the most during landing which is significant as the primary purpose of the ACL is to prevent anterior shear force of the tibia on the femur during motion. Fatigue may prove to be a predominant risk factor for ACL injuries.

Keywords*- anterior cruciate ligament, fatigue, kinetics, knee*

I. INTRODUCTION

Females are 2 to 8 times more likely to injure their anterior cruciate ligament (ACL) than their male counterparts (1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15), In particular, females are far more likely to sustain a noncontact ACL injury during sports participation activities that require frequent acceleration, deceleration, jumping, landing and changes of direction (2, 6, 7, 12, 13). Possible risk factors associated with noncontact ACL injuries include environmental, hormonal, anatomical and neuromuscular (1, 8). Sport specific activities have also been implicated for the increased risk of ACL injury. During basketball, female high school athletes injure their ACL more often while jumping or landing (60%) than athletes participating in soccer (25%) (16). The most frequent ACL injury mechanism in soccer appears to occur during the cutting maneuver (7, 10, 16). This variation in potential injury mechanism may be due to the nature of the specific sport or to an inherent neuromuscular strategy of the athlete (10, 16).

In 2006, Sell et al. (27) published data suggesting females performed certain jumping and landing tasks with different neuromuscular and biomechanical characteristics at the knee joint than did their male counterparts (27). Women performed both reactive jumps and jumps requiring a right leg dominant athlete to move to their left in a manner which might increase the strain on the ACL and possibly place the ligament at risk for injury.

Differences have been noted between the dominant and non-dominant lower extremities during sporting activity. In the sport of soccer, athletes are trained to use both legs to maneuver the soccer ball around the field, so the dominant leg was defined as the leg one would step out to catch themselves from a fall. This study is attempting to determine if the dominant or non-dominant leg are at risk for injury during specific sporting force activities.

Neuromuscular factors appear to be the most influential reason for the discrepancy of injury rates between the genders (1, 17). Fatigue is associated with decreased knee proprioception and increased anterior tibial translation (18, 19). Muscle fibers have a decreased capacity to absorb energy when fatigued, thus causing the athlete to land with altered neuromuscular function including a stiffer knee and increased magnitude of forces leading to the possibility of injury (18, 20, 21). Therefore, neuromuscular fatigue can impair the effects of dynamic joint stabilization and the body's inherent protection from injury (18, 21, 22, 23, 24).

An increase in tibial translation has been documented following an isokinetic fatigue protocol of the quadriceps femoris and hamstring muscles (18, 25). The findings suggest isokinetic muscle fatigue decreases dynamic knee stability possibly exposing the female athletes to an increased incidence of knee injury (18, 21, 22, 23, 24). Research has suggested a large number of ACL injuries occur in the later stages of athletic competition suggesting fatigue has some involvement in the mechanism of ACL injuries (17, 18, 26).

A majority of the research completed in association with fatigue surrounding the knee has utilized isokinetic protocols to induce fatigue in individual muscles (23, 24, 25). Many of the protocols involved open kinetic chain activities and isolated joint motions and muscle groups, thus the applicability to actual game situations and sports play has been questioned (24). The majority of sporting motions involve close chain kinetic activity and multiple joint movements involving a complex network of muscular actions. This study utilized a functional fatigue protocol to simulate practice/game fatigue, hence improving external validity.

The purpose of this study was to determine the effects of a functional fatigue protocol on vertical and shear ground reaction forces to better understand the knee injury phenomenon.

II. Methods

A. Participants

Eleven healthy, adult female collegiate soccer athletes participated in this study. Subject height, mass, and age were: 167.4 (±4.8) centimeters, 63.7 (±7.7) kilograms, and 20.3 (±0.9) years. All participants reported being free of ligamentous, bony, or cartilaginous injury in either knee for at least 6 months prior to participation. Women with previous anterior cruciate ligament injuries were excluded from participation. The subjects were in good physical condition and accustomed to participating in running, sprinting, change of direction and deceleration speed drills during soccer practice and games. Prior to the execution of the study, all participants were verbally informed of the details of the study and required to read and sign an informed consent document approved by an Institutional Review Board for the use of Human Subjects.

B. Instrumentation

The ground reaction forces were collected with two in-ground force plates. The force plates (Kistler, Type 9821C) were sampled at 1250 Hz. Variables obtained from the force plates included peak X, Y, and Z landing and push-off forces for each leg. The global coordinate force plate orientations for each force plate are depicted in Figure 1.

C. Procedures

Each of the participants reported to the lab and completed a one-time data collection. All subjects participating in the study performed a similar warm-up protocol on a grassy field adjacent to the biomechanics lab. The participants were introduced to the jump, land and cut maneuver. The athletes were given several practice attempts to master the skill of jumping over a barrier to land on the force plates.

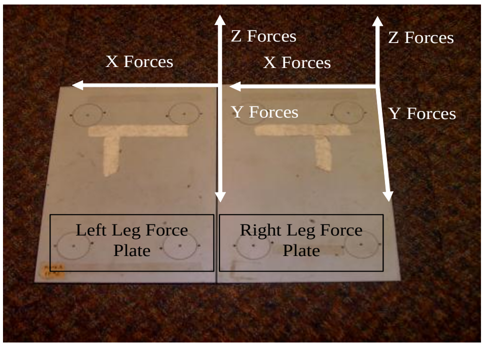

Figure 1. Ground Force Plate Global Coordinate System. X Forces are medial-lateral; Y Forces are anterior-posterior; and Z Forces are vertical (body weight normalized) for both the left and right force plates.

The force plate jump distance was approximately 120-150 cm and was marked with taped lines on the floor so consistency was maintained for all subjects during testing. The subjects were instructed to land after the jump with a one foot on each of the two force plates. Congruent with landing, subjects were shown a light to orient the cutting movement in one of three directions (45 degrees to the right, straight ahead, 45 degrees to the left). Subjects were instructed to perform a side-cut by stepping and cutting with the same foot as the light directed. For the center cut, the athletes were free to choose a preferred foot with which to lead. The athletes were tested with nine jumps, 3 jumps in each of the directions presented in a randomized fashion to gather pre-fatigue data on all participants.

The fatiguing protocol consisted of three tests. The first activity was the T-Test, an agility drill in which participants run and touch a series of cones arranged in a “T” shaped pattern (7). The second test, the 300-Yard Shuttle, was initiated 30 seconds following completion of the T-Test (7). The third test, the Repeated Sprint Ability Test, was initiated 30 seconds following the completion of the 300-Yard Shuttle run (28). The test consisted of 20 meter sprints departing every 20 seconds. The participants were instructed to stop as quickly as possible after every 20-meter sprint, similar to the rapid deceleration experienced during athletic participation. After completion of the third test, the participants were instructed to perform T-Tests until the fatigue criteria were reached. The fatigue criteria required a heart rate at or above 90% of age predicted heart rate max and a Rating of Perceived Exertion (Borg) of 17 or higher.

Immediately following the functional fatigue protocol, the participants completed the jump, land and cut maneuver as was performed in the Control Activity. After each jump, land and cut maneuver the heart rate was checked to maintain the specified fatigue level. If the participant’s heart rate dropped below the specified fatigue level, they were asked to repeat the T-Test until they reached the desired fatigue level.

D. Statistical Analysis

A 2-way analysis of variance (ANOVA) was used to examine the changes in ground force data during jump, land, and cut maneuvers in non-fatigued and fatigued states. A post hoc paired t-test was performed for each variable to determine the effects of the dominant leg and non-dominant leg. A separate post hoc paired t-test was performed for each variable to determine the effects of non-fatigue and fatigue. The dependent variables for statistical analysis were peak X, Y, and Z forces at landing and at push-off. An α=0.05 was chosen to denote statistical significance. All statistical analyses were completed using SPSS, version 15.0.

III. RESULTS

Ground reaction forces (landing and push-off) for fatigued and non-fatigued states as expressed with dominant and non-dominant legs for each of the three directions (left, center, and right cuts) are represented in Figures 2, 3, and 4 respectively. For each of the graphs, a single marker (*) was used to denote significance between the dominant v. non-dominant legs and a double marker (**) was used to denote significance between the non-fatigue and fatigue states. The graphs provide mean and standard error for X-medial-lateral (Newtons), Y- anterior-posterior (Newtons), and Z-vertical forces (normalized to bodyweight).

A. Landing

1) Left Cut

The dominant leg had significant effects for non-fatigue (p=0.000) and fatigue (p=0.000) states for the X (medial-lateral) forces. During the land the forces occurred in a medial direction with an 11% increase in medial forces seen in the fatigue state. The Y (anterior-posterior) direction landing forces for the dominant leg occurred in an anterior direction with 10% greater forces seen in the fatigue state. The dominant leg was found to have significant force values for fatigue (p=0.009). Fatigue effected the Z (vertical) direction forces for the dominant leg during landing (p=0.000). A 10% increase in vertical ground force was noted in the fatigue state in the dominant leg.

2) Center Cut

In the dominant leg, fatigue appeared to have a significant impact on the landing forces in the Y direction during the center cut (p=0.001). Landing forces for the dominant leg in the Y direction for landing were 22% greater in the fatigue state, suggesting greater anterior landing during fatigue. No significant findings were noted for the center cut in the X direction or the Z direction for either fatigue or leg dominance.

3) Right Cut

The landing forces in the Y direction were significantly effected by fatigue during the landing (p=0.009). The subjects landed with forces in the anterior direction, and a 23% increase in the landing forces were present from the non-fatigue to fatigued states. No significant findings were found for fatigue or leg dominance during the right cut in the X direction or Z direction.

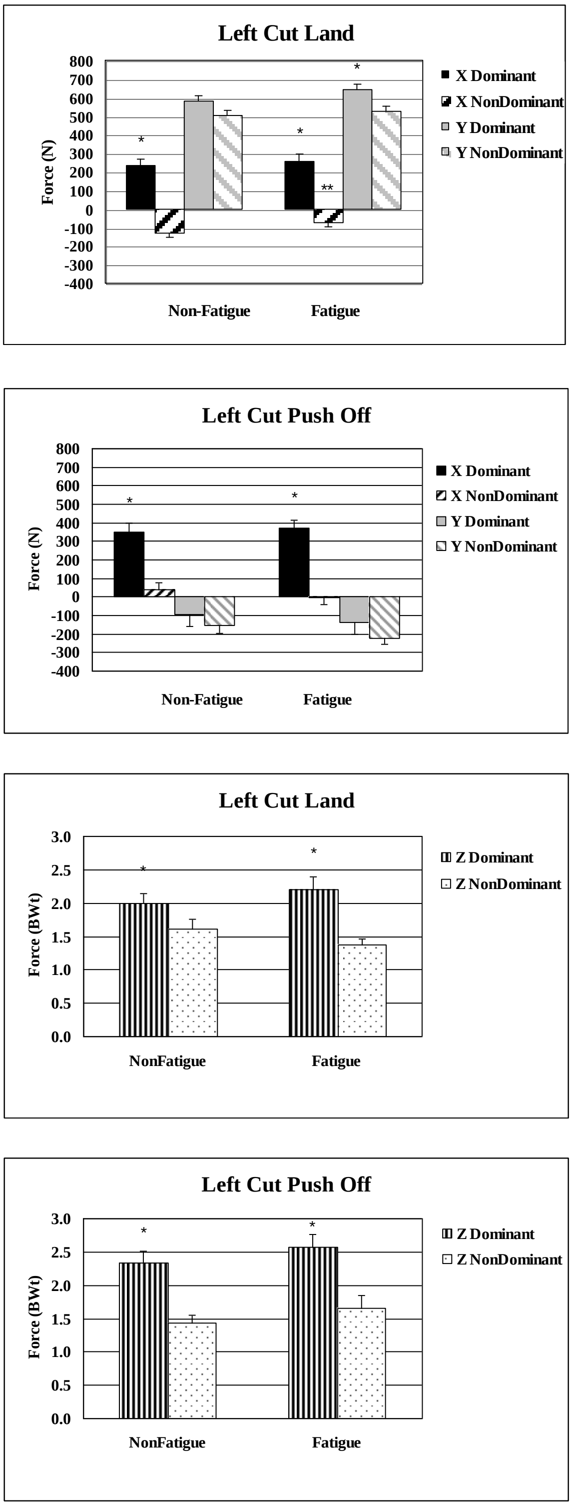

Figure 2. Means and standard error for left cut land and push off.

B. Push-Off

1) Left Cut

In the Z direction push off forces, fatigue played a significant role for the left cut (p=0.001) of the dominant leg and a 10% increase in vertical force production occurred from a non-fatigue to fatigue state. The non-dominant leg had less force production than the dominant leg suggesting a diminished impact during the left cut. Neither the X direction or the Y direction were noted as having statistical significance during the left cut push off for fatigue or leg dominance.

2) Center Cut

Fatigue had a significant impact on the forces of the Z direction push off forces for the non-dominant leg (p=0.001) and the magnitude of the force production increased over 31% from a non-fatigue state to fatigue. The X direction and Y direction had no significant values for fatigue or leg dominance in the center cut push off.

3) Right Cut

Fatigue increased the force magnitude for the X direction by 106% for the dominant leg. The results were not statistically significant, but the data suggests the subjects were pushing off for the right cut with a medial force in the non-dominant leg. No statistical significance was noted for the X, Y or Z directional forces for either the fatigue state or the leg dominance conditions.

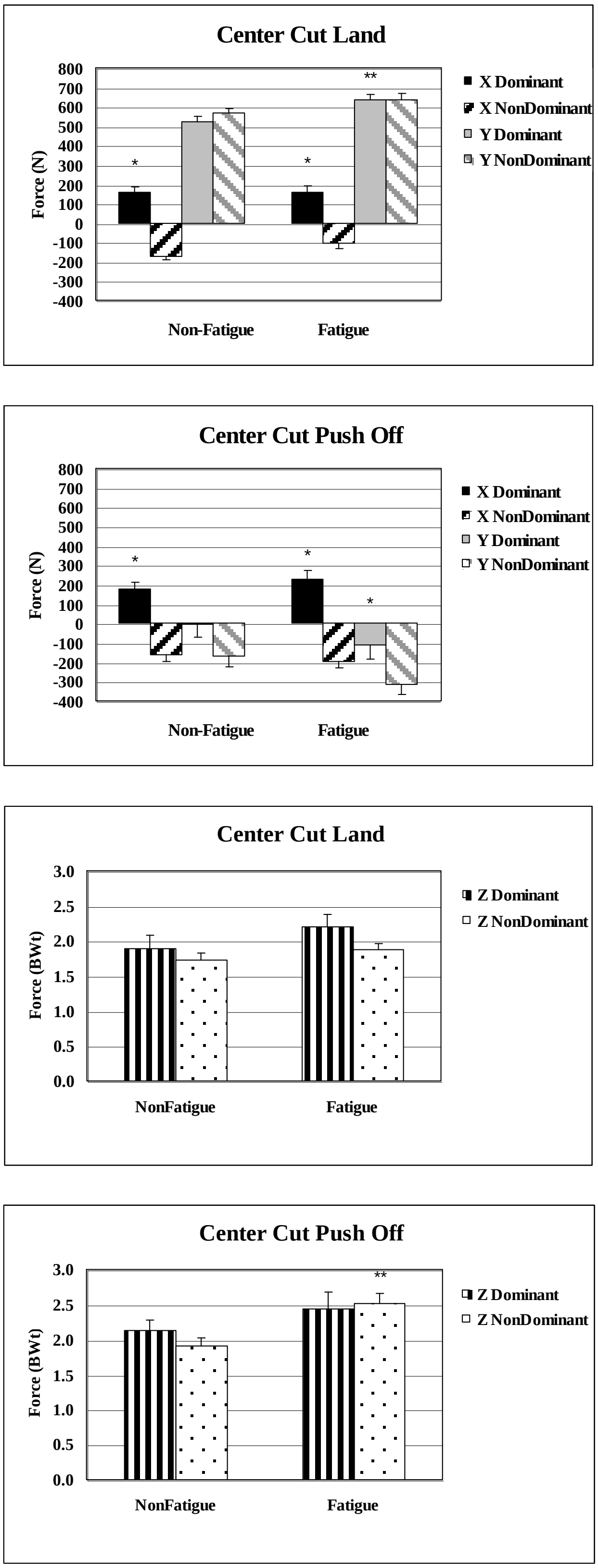

Figure 3. Means and standard error for center cut land and push off.

IV. DISCUSSION

The purposes of this study was to determine the effects of fatigue on ground reaction forces for the dominant and non-dominant legs during jump, land, and cut tasks. These tasks have been implicated in the mechanism of ACL injury. The significant findings in this study are the results of the effects of fatigue and leg dominance on the sport specific tasks during the trials. The direction of the cut failed to show any significant differences; however, the center cut had the greatest number of statistically significant results between the non-fatigued and fatigued trials and the left cut had the greatest number of statistically significant results between the dominant and non-dominant legs during trials.

A. Landing

Fatigue had a significant effect on the biomechanical characteristics of the knee during landing. During landing the most significant finding was noted in the anterior-posterior forces for each cutting direction. The primary purpose of the ACL is to restrain anterior tibial translation of the tibia on the femur. The ACL plays a very important functional role in the stabilization of the knee joint during movement. The most common ACL injury mechanisms have been described as a sudden deceleration, abrupt change in direction, hyperextension, or landing from a jump. If the knee is receiving large shearing forces in an anterior-posterior direction during a landing this might be a perfect example of the ACL being at risk for injury during landing tasks.

Landing differences also were noted in the medial-lateral direction; however, results did not reach statistical significance. The secondary anatomical function of the ACL: assists with rotatory knee stability; the prevention of valgus or varus knee laxity; and serves as a femoral guiding component on the tibia during terminal extension (screw-home mechanism) suggesting a practical significance to the data our study collected.

Past studies (2, 17, 27) have attempted to determine the effects of landing on the knee joint during athletic activity. Decker et al. (2) examined the differences in lower extremity kinetics and energy absorption during landing. The females who participated in the study were found to land with greater energy absorption than males. The knee was found to be the primary shock absorber for both genders, and the ankle plantar-flexors muscles were the second largest contributor to energy absorption for the females whereas the hip extensor muscles were second for the males. Although kinematic data was not collected during our study, it appears the female athletes were landing with significant landing forces. Chappell et al. (17) examined the effects of fatigue on landing kinetics during 3 stop-jump tasks. While significant increases were found for both male and female subjects, females were reported to have a 94% increase in tibial anterior shear force and a 96% increase in knee valgus moment during fatigue states as compared to their male counterparts. No data was collected on male subjects during our study; however, significant results were noted for all three cut directions during the landing in the anterior direction with left cut (p=0.049), center cut (p=0.000), and right cut (p=0.009). Our results suggest fatigue had a significant influence on the anterior shearing forces regardless of cut direction. These anterior shear forces may indicate a potential hazard for the ACL placing the structure at risk for injury during athletic movement. Our study split the land and push off phases into separate entities whereas no mention was given in the Chappell et al. study to suggest the different stages of force production were analyzed. During push off analysis, the anterior direction of the dominant leg experienced a substantial increase in force magnitude with the introduction of fatigue (>100 Newtons). However, due to the large variability surrounding the mean increase in anterior shear force due to fatigue, the results did not achieve statistical significance. Interestingly, the high variability around the anterior shear force measure might suggest it is a contributing factor to injury. No kinematic data was collected to indicate the valgus or varus movement of the knee during athletic tasks in our study. Sell et al. (27) was one of the first researchers to focus on straight landing tasks during planned and unplanned jumps in different directions (left, right, or vertical). Jumps to the left had the greatest vertical and posterior ground reaction forces compared with the vertical jump and jumps to the right. The vertical jumps showed significantly greater vertical and posterior ground reaction forces then the jumps to the right. The data collected in our study appear to support larger vertical and posterior ground reaction forces in the left cut over the center or right cut as well in the dominant leg. The medial ground reaction forces during the left cut in our study, suggested the dominant knee might be at a greater risk of injury during the left cut than the other two cutting directions. For the non-dominant leg, the left cut demonstrated the lowest medial, posterior and vertical ground reaction forces. Only the right leg was analyzed in the Sell et al. study, therefore, it is plausible to assume our findings might explain the force production occurring in the dominant and non-dominant legs during athletic movement.

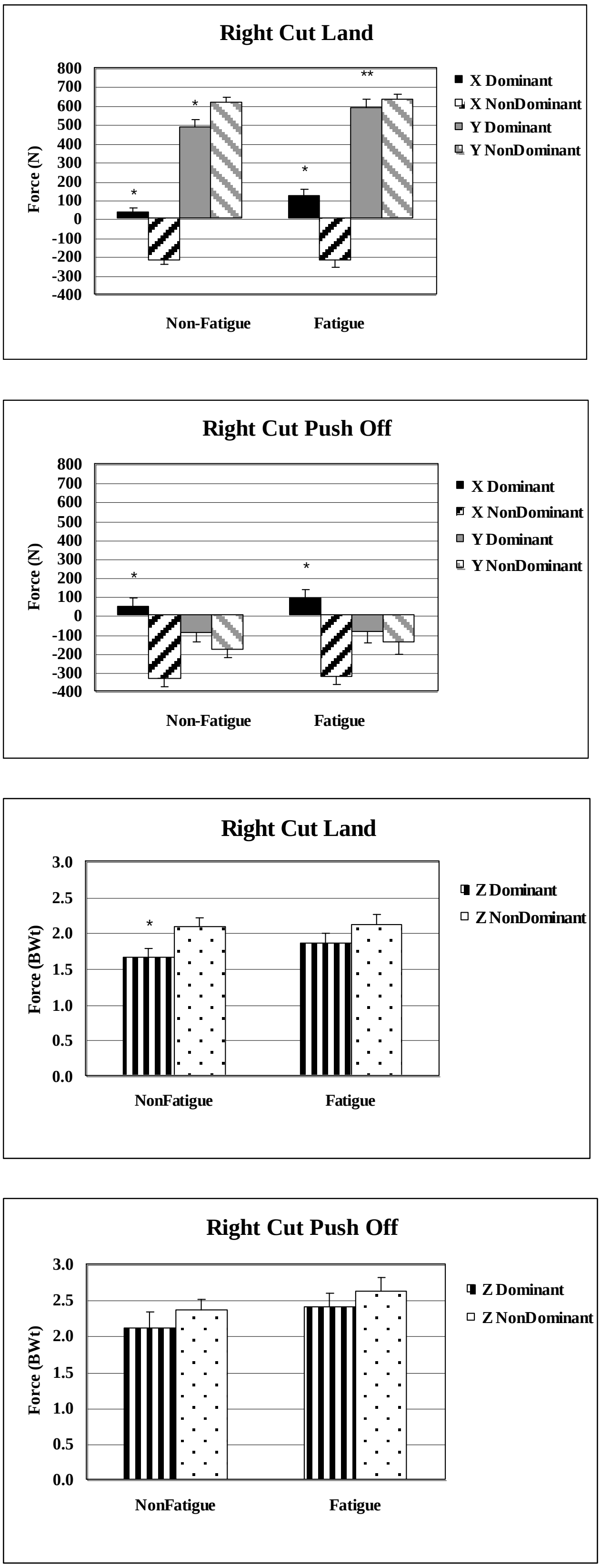

Figure 4. Means and standard error for right cut land and push off.

Jump landing forces have been suggested as a component of the noncontact ACL injury mechanism. The force magnitude for the dominant limb was greatest during the left cut landing suggesting the majority of forces during the left cut were coming from the right leg. The force magnitude for the non-dominant limb was greatest in the right cut land suggesting the left leg sustained the greatest amount of force. During the center cut, the dominant leg and non-dominant leg had magnitude values much closer to each other suggesting a center cut landing occurs with a limb distribution that is nearly equal. The limbs appear to have different landing strategies when given a stimulus for an unplanned cut. The data suggests the dominant and non-dominant limbs do not have the same force distribution when landing and cutting as frequently occurs during sports activities such as soccer.

B. Push Off

Fatigue appeared to have a significant effect on the biomechanical characteristics of the vertical ground reaction forces during push off for all three cutting directions. The fact that we did not find any statistically significant findings in the vertical direction during landing might suggest a sport-specific component of soccer. In an earlier study, Cowley et al. (16) suggested ACL injury mechanism was sport specific with basketball athletes injuring the ACL during jump and landing and soccer athletes most frequently injuring the ACL during cutting tasks. The push-off value recorded should be the moment when the cutting maneuver begins. Fatigue was associated with the increase in vertical force magnitude during push off supporting earlier research completed by Cowley et al. suggesting a sport specific component is responsible for the noncontact ACL injury mechanism.

Several studies (16, 21, 29, 30) have focused on an athletic change of direction task; however, very few studies have centered on the biomechanical characteristics among different directional movements. Besier et al. (29) examined the external loading of the knee joint at 30 and 60 degrees during running and cutting tasks. Comparisons between this study and Besier's are limited due to the subject pool and difference in task requirements, but significance was noted in ground-reaction forces among the different tasks. Ford et al. (30) examined the gender difference in the kinematics of unanticipated cutting. Significance was found in knee and ankle kinematics in the frontal plane during cutting. Chappell et al. (21) examined stop-jump tasks performed in three directions: vertical, forward, and backward. Although the study did not address lateral movements, significant differences were noted in anterior tibial force based on jump direction. Cowley et al. (16) examined the differences in neuromuscular landing and cutting strategies among specific sport athletes. The researchers noted an average increase of in peak vertical ground reaction force (15.6%) and a decrease in stance time (20.5%) in soccer players during the cut compared with basketball players. In contrast, the basketball players had greater ground reaction forces (12.5%) during landing and a decrease in stance (14.6%) compared with soccer players. In both the soccer and basketball athletes, greater valgus moments occurred during cutting on the dominant side. The mean valgus moment was 31.8% greater on the dominant side than on the non-dominant side during the cut. The mean vertical ground reaction force for the cut was 41.4% greater on the dominant side than the non-dominant side. The data collected in our study did not necessarily mimic the data collected by Cowley et al. for vertical ground reaction forces data. Our tasks were significantly different as Cowley used a vertical drop jump whereas our study implemented a dynamic jump component; therefore applicability to this study is slightly limited. The Cowley et al. study calculated valgus moment suggesting subjects experienced a medial force when landing. The data collected in our study supported Cowley et al. as our subjects landed with medial forces as well during the jump procedure. During the cutting, differences were noted again for cutting direction. The left cut push off was initiated with the greatest forces occurring to the dominant leg. The data suggests the right leg is at the greatest risk of injury during the left cut push off. The right cut was initiated with the greatest forces occurring in the non-dominant limb, suggesting the left leg could be at risk for injury during the cut.

In the center cut, a substantial increase in mean anterior force magnitude was noted (>100 Newtons) with the introduction of fatigue suggesting the subjects were unprepared to make a cut towards the center direction. It appears the subjects hesitated, requiring many of the subjects to rock back on the heel before initiating a cut to the center instead of remaining on the toes to initiate the cut. In the center cut, the non-dominant limb had slightly higher magnitudes than the dominant leg did for the push off.

V. CONCLUSIONS

Fatigue had a significant effect on landing forces during unplanned cutting maneuvers. The dominant or non-dominant extremity had different force magnitudes according to directional cutting. Future studies should incorporate unplanned cutting maneuvers and other fatiguing protocols. The average soccer player engages in endurance fatigue protocols throughout practice and games rather than the rapid fatiguing protocol the athletes were subjected to in order to induce fatigue. A sport-specific fatigue protocol might help to determine the fatigue component and suggest further risk factors for ACL injury and the appropriate training intervention protocol to reduce the incidence of noncontact ACL injuries in the female athlete. In addition, research has suggested muscular imbalances occurring in the quadriceps and hamstring muscles might be a possible risk factor for ACL injury; however, limited research has suggested any meaningful correlation between injury and strength ratios. Future research would benefit from assessing the effect of muscular strength and imbalance on ground reaction forces during non-fatigue and fatigue states.

REFERENCES

[1] Anderson, A., Dome, D., Gautam, S., Awh, M., & Rennirt, G. Correlation of anthropometric measurements, strength, anterior cruciate ligament size, and intercondylar notch characteristics to sex differences

in anterior cruciate ligament tear rates. *The American Journal of Sports Medicine*. 2001;29(1):58-66.

[2] Decker, M. et al. Gender differences in lower extremity kinematics, kinetics, and energy absorption during landing. *Clinical Biomechanics*. 2003;18(662-669).

[3] Huston, L. & Wojtys, E. Neuromuscular performance characteristics in elite female athletes. *The American Journal of Sports Medicine*. 1996;24(4):427-436.

[4] Hutchinson, M. & Ireland, M. L. Knee injuries in female athletes. The *Journal of Sports Medicine*. 1995;19(4):288-302.

[5] Junge, A. & Dvorak, J. Soccer injuries: A review on incidence and prevention. *The Journal of Sports Medicine*. 2004;34(13):929-938.

[6] McLean, S., Su, A., & Van den Bogert, T. ACL injury: Sagittal plane biomechanics are not the cause. *Clinical Biomechanics*. 2003;19:828-838.

[7] Moeller, J., & Lamb, M. Anterior cruciate ligament injuries in female athletes: Why are women more susceptible? *The Physician and Sportsmedicine*. 1997;25(4):1-8.

[8] Piasecki, D., 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. *The American Journal of Sports Medicine*. 2003;31(4):601-605.

[9] Pollard, C., Davis, I., & Hamill, J. Influence of gender on hip and knee mechanics during a randomly cued cutting maneuver. *Clinical Biomechanics*. 2004;19:1022-1031.

[10] Powell, J., & Barber-Foss, K. Sex-related injury patterns among selected high school sports. *The American Journal of Sports Medicine*. 2000;28(3):385-391.

[11] Rozzi, S., Lephart, S., Gear, W., & Fu, F. Knee joint laxity and neuromuscular characteristics of male and female soccer and basketball players. *The American Journal of Sports Medicine*. 1999;27:312-319.

[12] Slauterbeck, J., et al. The menstrual cycle, sex hormones, and anterior cruciate ligament injury. *The Journal of Athletic Training*. 2002;37(3):275-278.

[13] Toth, A., & Cordasco, F. Anterior cruciate ligament injuries in the female athlete. *Journal of Gender Specific Medicine*. 2001;4(4):25-34.

[14] Wojtys, E. et al. Gender differences in muscular protection of the knee in torsion in size-matched athletes. *The Journal of Bone and Joint Surgery*. 2003;85:782-789.

[15] Wojtys, E., Wylie, B., & Huston, L. The effects of muscle fatigue on neuromuscular function and anterior tibial translation in healthy knees. *The American Journal of Sports Medicine*. 1996;24(5):615-621.

[16] Cowley, H., Ford, K., & Myer, G. Differences in neuromuscular strategies between landing and cutting tasks in female basketball and soccer athletes. *The Journal of Athletic Training*. 2006;41(1):67-73.

[17] Chappell, J., et al. Effect of fatigue on knee kinetics and kinematics in stop-jump tasks. *The American Journal of Sports Medicine*. 2005;33(7):1022-1029.

[18] Rowe, A., et al. Effects of a 2-hour cheerleading practice on dynamic postural stability, knee laxity, and hamstring extensibility. *Journal of Orthopaedic & Sports Physical Therapy*. 1999;29(8):455-462.

[19] Wojtys, E. & Huston, L. Neuromuscular performance in normal and anterior cruciate ligament-deficient lower extremities. *The American Journal of Sports Medicine*. 1994;22(1):89-104.

[20] Ahmad, C., Clark, M., Heilmann, N., & Schoeb, S. Effect of gender and maturity on quadriceps-to-hamstring strength ratio and anterior cruciate ligament laxity. *The American Journal of Sports Medicine*. 2006;34(3): 370-374.

[21] Chappell, J., Yu, B., Kirkendall, D., & Garrett, W. A comparison of knee kinetics between male and female recreational athletes in stop-jump tasks. *The American Journal of Sports Medicine*. 2002;30(2):261-267.

[22] Madigan, M. & Pidcoe, P. Changes in impact force and joint torques during a fatiguing landing activity. *American Society of Biomechanics*. Toledo, OH. 2003;September 25-28.

[23] Nyland, J. et al. The effect of quadriceps femoris, hamstring, and placebo eccentric fatigue on knee and ankle dynamics during crossover cutting. *The Journal of Orthopaedic and Sports Physical Therapy*. 1997;25(3):171-184.

[24] Wikstrom, E., Powers, M., & Tillman, M. Dynamic stabilization time after isokinetic and functional fatigue. *The Journal of Athletic Training*. 2004;39(3)247-253.

[25] Hahn, T., Foldspang, A., & Ingemann-Hansen, T. Dynamic strength of the quadriceps muscle and sports activity. *The British Journal of Sports Medicine*. 1999;33:117-220.

[26] Aagard, P. et al. Antagonist muscle coactiviation during isokinetic knee extension. *Scandinavian Journal of Medicine and Science in Sports*. 2000;10:58-67.

[27] Sell, T. et al. (2006). The effect of direction and reaction on the neuromuscular and biomechanical characteristics of the knee during tasks that simulate the noncontact anterior cruciate ligament injury mechanism. *The American Journal of Sports Medicine*. 2006;34:43-54.

[28] Wadley, G. & LeRosignol, P. The relationship between repeated sprint ability and the aerobic and anaerobic energy systems. *Journal of Science and Medicine in Sport*. 1998; 1(2):100-110.

[29] Besier, T., Lloyd, D., Cochrane, J., & Ackland, T. External loading of the knee joint during running and cutting maneuvers. *Medicine & Science in Sports & Exercise*. 2000;33(7):1168-1175.

[30] Ford, K., Myer, G., Toms, G., & Hewett, T. Gender differences in the kinematics of unanticipated cutting in young athletes. *Medicine & Science in Sports & Exercise*. 2005;37(1): 124-129.

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