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ACL Injuries—The Gender Bias

SAGITTAL-PLANE ALTERATIONS IN LANDING MECHANICS

Abstract #1

Ground Reaction Forces, but Not Knee Muscle Activation, or Sagittal Knee Joint Stiffness Differ Between Female Dancers and Basketball Players during Drop Jumps

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Introduction: Anterior Cruciate Ligament (ACL) injuries frequently occur during landing. Although both dancers and athletes regularly perform landings, dancers reportedly have lower rates of ACL injury than athletes. During activity, greater knee muscle coactivation can increase knee joint stiffness, and be protective by not allowing the joint to reach harmful ranges. Dancers have been reported to demonstrate diminished H-reflexes (indicating higher muscle coactivation levels) than active controls. Whether dancers use different neuromuscular strategies than athletes that may modify knee joint stiffness and allow for ACL-injury protection during activity is still unknown. Thus, we compared lower extremity muscle activation, sagittal knee joint stiffness (KJS), and ground reaction forces (GRFs) between female dancers and basketball players during the initial landing phase of a double-leg drop jump.

Methods: 35 dancers (20.7+2.3 yrs, 164.3+6.7 cm, 62.2+1.9 kg, experience=13.9+5.2 yrs) and 20 basketball players (20.1+2.0 yrs, 170.5+6.1 cm, 72.6+11.4 kg, experience=10.7+3.5 yrs) performed 5 double-leg drop jumps from a 45 cm box in a controlled laboratory setting. Muscle activity was recorded via surface electromyography to obtain muscle onset times and activation amplitudes for the lateral gastrocnemius (LG), medial and lateral hamstring (MH, LH) and lateral quadriceps (LQ) muscles. A force plate and 3D electromagnetic tracking system were used to record kinetic and kinematic data to calculate KJS and GRF. All measurements were taken on the preferred landing leg. Muscle activation amplitudes were defined as the mean RMS amplitudes (100 ms time constant; ms), normalized to maximum volitional isometric contractions (%MVIC). Muscle onsets (ms) were defined as time prior to ground contact when muscle activity exceeded 5 standard deviations above quiet standing baseline activity for at least 25 ms. KJS was calculated as the ratio of the change in sagittal knee moment normalized to body weight (Nm/kg) to the change in sagittal knee flexion angle (°) from ground contact to maximum knee flexion (Nm/kg°). GRFs were expressed in body weights (BW). Separate 2×4 ANOVAs compared dancers and basketball players on muscle onsets times and muscle activation amplitudes both before (*pre= 150 ms*) and after (*post= 50 ms*) ground contact. Two separate one-way ANOVAs examined group differences in KJS and peak GRFs.

Results: No group differences were observed in muscle onset times (dancers=133.4±53.2 ms, basketball players=121.6±50.2 ms; *P=.22*), activation amplitudes (*pre*: dancers=28.1±8.7%MVIC, basketball players=27.7±10.5%MVIC; *P=.60*; *post*: dancers=51+17.3%MVIC, basketball players=49.6±21.4%MVIC; *P=.78*), or KJS (dancers=.016±.01 Nm/kg°, basketball players=.018+.01 Nm/kg°; *P=.44*). Dancers had higher peak GRFs than basketball players (dancers= 4.26±.9BW; basketball players=3.68±.6BW; *P=.01*).

Discussion: While muscle activation amplitudes did not differ statistically between groups, effect size calculations indicated that dancers had higher muscle activation in MH (*pre*: 34 vs.26%MVIC, ES=.55; *post*: 38 vs.25%MVIC, ES=.41) and LG (*post*: 45 vs.35%MVIC, ES=.33), and lower activation levels in LQ (*post*: 97 vs.109%MVIC; ES=.30).The absence of significant findings was thus probably in part due to low statistical power. Further, although KJS did not differ between groups, higher GRFs noted in dancers may indicate differences in joint energy absorption strategies across other lower extremity joints.

Conclusions: Although no significant differences were noted in muscle activation or knee joint stiffness between dancers and basketball players, trends were observed towards higher hamstring and lower quadriceps muscle activations in dancers. Continued research is needed to determine possible ACL-injury protective mechanisms employed by dancers during high ACL-risk activities including landing, jumping, and reactive plant-and-cut maneuvers.

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Abstract #2

Influence of Ankle Dorsiflexion Range of Motion and Lower Leg Muscle Activation on Medial Knee Displacement During a Double-Legged Squat

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Introduction: Medial knee displacement (MKD) may predispose individuals to ACL injury and patello-femoral pain. Limited ankle dorsiflexion range of motion (DF-ROM) and increased lateral gastrocnemius (LG) activation are proposed to increase

MKD. However, research has not investigated the influence of DF-ROM and lower leg muscle activation on MKD. Our purpose was to compare lower leg muscle activation amplitude and DF-ROM between individuals who display MKD to those who do not. We hypothesized that individuals demonstrating MKD will have increased LG activation during a double-legged squat (DLS) and decreased DF-ROM compared to those who do not. We also hypothesize that placing a 2-inch lift under the calcaneus will alter lower leg muscle activation during a DLS.

Methods: Thirteen participants exhibiting MKD (ht = 161.7 ± 6.4 cm, m = 61.6 ± 7.5 kg, age = 22.0 ± 1.2 yrs) and fourteen control participants (CON) who demonstrated no MKD (ht = 161 ± 3.6 cm, m = 60.7 ± 4.21 kg, age = 20.7 ± 1.8 yrs) participated in the study. Prior to testing participants performed a DLS under no-lift (NL) and lift (L) conditions. Inclusion criteria for the MKD group included: 1) presence of MKD during the NL DLS and 2) no MKD during the L DLS. All CON group subjects did not display MKD during the NL and L DLS conditions. During the NL DLS the subjects stood with their feet shoulder width apart, toes pointed straight ahead, arms above their head, and were instructed to squat down as if sitting in a chair. Identical instructions and positioning were employed during the L DLS with the addition of a 2-inch lift placed under the heel. Five trials of the DLS were performed for the L and NL conditions. Surface EMG quantified the average amplitude (%MVIC) for the LG, medial gastrocnemius (MG), and tibialis anterior (TA) muscles during DLS tasks. A goniometer was used to measure DF-ROM with the knee extended and flexed 30°. 2×2 repeated measures ANOVAs were used to compare the MKD and CON groups and the L and NL DLS tasks for each dependent variable.

Results: We observed a main effect for group ($P = 0.03$) with increased TA activity in the MKD (51.89 ± 3.99%MVIC) compared to the CON (39.15 ± 3.85%MVIC) during the descending phase of the squat. When the squat was performed on the heel lift muscle activation decreased significantly in the MG (NL: 24.65 ± 2.31%MVIC, L: 18.10 ± 2.24%MVIC, $P < 0.001$), LG (NL: 23.25 ± 2.80%MVIC, L: 15.75 ± 2.19%MVIC, $P < 0.001$), and TA (NL: 58.89 ± 3.96%MVIC, L: 32.41 ± 3.01%MVIC, $P < 0.001$). No differences in ankle dorsiflexion range of motion were observed between groups (MKD: 13.22 ± 1.87°, CON: 15.69 ± 1.80°, $P = 0.35$). No group by DLS condition interaction was observed for the LG ($P = 0.23$), MG ($P = 0.99$), or TA ($P = 0.70$).

Conclusions: Our original hypothesis was not supported. No interaction existed between LG activity and squat condition. Higher TA activity in the MKD group may be an attempt to control foot pronation. Theoretically, excessive pronation increases knee valgus by causing tibial internal rotation. However, this conclusion is speculative since we did not measure pronation. Performing the overhead squat on a heel lift decreased muscle activation in all muscles. The heel lift increases plantar flexion and alters the length-tension relationship of lower extremity muscles. Ankle dorsiflexion might still contribute to MKD due to group selection criteria.

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Abstract #3

The Effects of a Prophylactic Ankle Brace on Lower Extremity Biomechanics During Drop Landing

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Introduction: Ankle bracing is effective in preventing repeated ankle sprains in individuals who have previously sprained an ankle[1]. However, using a prophylactic ankle brace may lead to altered ground reaction forces, and restriction of tibial motion may alter knee joint kinematics that may potentially increase the risk of injury to the ACL. The purpose of this study was to determine the effects of prophylactic ankle bracing on lower extremity biomechanics in females during a drop landing.

Methods: Sixteen-female, recreational athletes participated in this study (n = 16; 21.2±2.9 yr, 57.9±8.2 kg, 164.8±7.6 cm). Double-leg drop landings (ht = 0.43 m) were performed while wearing or not wearing a prophylactic ankle brace (BR, NO-BR, respectively), with the dominant limb landing onto a force platform (1200 Hz). Kinematic data were recorded with 7 C-MOS video cameras (240 Hz). To compare the ankle and knee displacements (DISP), initial contact angles, and vertical GRF (VGRF) between BR and NO-BR landings, repeated-measures (RM) ANOVA were used ($p < 0.05$).

Results: For the RM ANOVA results, BR compared to NO-BR displayed, respectively, a greater peak VGRF (24.1±6.4 N/kg and 21±5.1 N/kg) and earlier time to peak VGRF (56.9±13.8 ms and 62.2±15.0 ms). Compared to NO-BR, BR exhibited a more flexed knee angle at initial contact (22±9° and 19±9°), and less angular DISP for knee flexion (51±13° and 54±11°), ankle flexion (39±6° and 50±7°) and ankle external rotation DISP (6±5° and 10±4°). Knee internal rotation decreased 2°, but only 5 participants displayed 2° to 7° less internal knee rotation during BR landings.

Discussion: The ankle brace restricted ankle flexion and external rotation DISP. Consequently, for some individuals, knee internal rotation during BR landings was also reduced that may have improved transverse plane alignment of the knee joint. Furthermore, as a more extended knee angle has been associated with ACL injury risk[2] and increased ACL loading[3], the more flexed knee position at contact during BR landings may be helpful. However, the greater peak VGRF during BR landings suggests a disadvantage, as greater VGRF magnitudes may increase ACL loading. Higher impact forces during BR landings were likely due to restricted ankle flexion that also decreased knee flexion DISP and reduced the time to peak VGRF. AB/ADD knee motions likely were not affected by the use of a BR.

Conclusion: Wearing a BR during landing activities may be helpful, as it allows the person to land in a more flexed knee position and reduce internal knee rotation DISP, but increased VGRF are a disadvantage. BR effects on ACL loading and injury mechanisms will need to be substantiated.

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Abstract #4

Stiff Landing Increases Frontal Plane Loading of the Knee

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Introduction: Knee valgus motion and moments have been shown to be predictors of non-contact ACL injury[2]. It has been proposed that females lack the strength and/or neuromuscular control of the sagittal plane musculature to effectively decelerate

Table 1.

	R	R^2	Adj. R^2	Std. Error Estimate	ANOVA p-value	Regression Equations
Males	0.726	0.527	0.510	0.322	<.001	Y = .496*GRFv + .026*TFA + 1.211
Females	0.863	0.744	0.735	0.237	<.001	Y = .634*GRFv + .036*TFA + .974

*Predictors included in the model are ground reaction force (GRFv) and trunk flexion angle (TFA).

the body center of mass during landing tasks. More specifically, it is thought that females limit the amount of hip and knee flexion during these tasks, and instead, rely more on their passive restraints in the frontal plane (i.e. ligaments) for control[1]. The purpose of this study was to examine differences in knee and hip kinematics and kinetics between females who exhibit a "stiff land" strategy versus those who exhibit a "soft land" strategy.

Methods: Subjects consisted of 58 healthy female club soccer players ranging in age from 11 to 17 years (average age 13.5 yrs). Three-dimensional kinematics (eight camera Vicon system, 250 Hz), ground reaction forces (AMTI, 1500 Hz), and surface electromyography (EMG) were collected while each subject performed a drop landing task (3 trials). Kinematics and net joint moments at the knee and hip were calculated using Visual 3D™ software. In order to compare lower extremity mechanics between subjects who utilized a "soft land" versus a "stiff land," subjects were divided into groups based on their combined peak knee and hip flexion angles during the landing task. Subjects who exhibited a combined hip and knee flexion value above the sample average were assigned to the "soft land" group (27 subjects) and those who exhibited a value below were assigned to the "stiff land" group (31 subjects). Variables of interest included the peak knee valgus angle, average internal knee adductor moments, knee extensor moments, hip extensor moments, and average EMG for the vastus lateralis and hamstrings during the deceleration phase of landing. Differences between groups were evaluated using independent sample t-tests. Significance levels were set at $P \leq 0.05$.

Results: Subjects in the "stiff land" group demonstrated increased peak knee valgus angles (6.15 ± 4.42° vs. 3.96 ± 3.81°) ($P=0.02$), increased average knee adductor moments (0.137 ± 0.179 Nm/kg vs. 0.055 ± 0.142 Nm/kg) ($P=0.03$), increased average knee extensor moments (1.370 ± 0.278 Nm/kg vs. 1.240 ± 0.232) ($P=0.03$), increased vastus lateralis muscle activation (89.98 ± 53.14% MVIC vs. 59.17 ± 23.49% MVIC) ($P<0.01$) and decreased average hip extensor moments (0.657 ± 0.241 Nm/kg vs. 0.853 ± 0.171) ($P<0.01$) when compared to subjects in the "soft land" group.

Discussion: Our data indicate that individuals who utilize greater sagittal plane hip and knee motion demonstrate less loading at the knee in the frontal plane. This finding is important since it has been shown that individuals who exhibit increased knee valgus angles and moments are at a greater risk of ACL injury. Furthermore, it appears that those individuals who select a "stiff land" strategy rely more on their knee extensors for sagittal plane deceleration as opposed to their hip extensors. We postulate that hip extensor weakness and/or poor control may contribute to this "stiff land" strategy and subsequent frontal plane loading at the knee. The current study provides support for the underlying framework of numerous ACL injury prevention programs which train females to land with increased sagittal plane motion. This emphasis may increase sagittal plane strength and control at the hip and knee as well as deter individuals from relying on their passive restraints.

Conclusions: Individuals who utilize a "stiff land" strategy exhibit increased knee valgus angles and valgus moments compared to those who utilize a "soft land." It appears that these individuals may select this pattern due to decreased hip strength and/or control.

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Abstract #5

Trunk Flexion Angle and Ground Reaction Force as Predictors of Knee Anterior Shear Forces in Males and Females

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Introduction: The sex disparity in ACL injuries is well documented. Anterior shear forces in the knee (ASFk) increase strain on the ACL. Therefore, an understanding of biomechanical variables influencing ASFk in males and females is warranted. Females have been suggested to land with a more erect trunk posture and with higher ground reaction forces as compared to males. An understanding of the influence of trunk posture and ground reaction forces on ASFk would lend insight into mechanistic pathways leading to potentially injurious forces on the ACL. The purpose of this project was to determine the independent and combined relationships between trunk flexion angle and vertical ground reaction force on peak ASFk in males and females.

Methods: 24 recreationally active and healthy males and females were instrumented for traditional biomechanical analysis. Subjects performed eight vertical drop jumps from a height of 45 cm while kinematics (240 Hz) and ground reaction forces (960 Hz) were collected. The first five acceptable trials as determined by the absence of visible marker dropout were exported and used for analysis. A five segment biomechanical model (trunk, pelvis, femur, tibia, foot) was constructed. Trunk angle was calculated as the angular orientation of the trunk segment relative to the vertical axis of the laboratory coordinate system (flexion = negative angle). Following inverse dynamics calculations, kinematic and kinetic variables were entered into a mathematical model to calculate ASFk for all trials (DeVita and Hortobagyi 2001). Trunk flexion angle (TFA) and vertical ground reaction force (GRFv) at the time of peak ASFk were entered into a stepwise regression to predict peak ASFk ($\alpha=.05$). Components of the full model regression equation were compared between sex ($\alpha=.05$). Bivariate correlations between ASFk/GRFv and ASFk/TFA were also compared between sex using Fisher's r to z transformation (Critical Z = 1.96).

Results: Zero-order bivariate correlations between peak ASFk and GRFv (males= .519; females= .636) were positive and significant from zero (P<.001) but not different between sex (Z=.94). Bivariate correlations between ASFk and TFA (males= .509; females= .566) were positive and significant from zero (P<.001) but not different between sex (Z=.43). For the stepwise regression analysis, GRFv entered into the models first and explained 27% (males) and 40% (females) of the variance in peak ASFk. TFA entered second into the models explaining an additional 26% (males) and 34% (females) of the variance in peak ASFk. For the full regression model, GRFv and TFA combined to explain 74% (females) and 51% (males) of the variance in peak ASFk. When comparing males and females for each of the components of the full model regression equations (Table 1), the intercepts (P=.39), B coefficients for GRFv (P=.21), and B coefficients for TFA (P=.14) were not statistically different.

Discussion: Although GRFv and TFA at the time of peak ASFk each had moderate correlations with peak ASFk, their combined explained variance was 74% in females and 51% in males. Clinical interpretation indicates that increasing trunk flexion angle while decreasing vertical ground reaction forces will lower the anterior shear forces in the knee. Overall, the results describe two mechanistic pathways combine to lead to high anterior shear forces in the knee.

Conclusions: While anterior shear forces in the knee are predicted by trunk posture and ground reaction force, the prediction is stronger in females compared to males. Future studies investigating the ability of TFA and GRFv to predict the incidence ACL injury are warranted.

SEX COMPARISONS IN LANDING AND CUTTING

Abstract #6

Lower Extremity Kinetic Differences During Drop-Jump Landings Between Prepubescent Males and Females

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Introduction: Literature has demonstrated lower extremity biomechanical differences between adolescent and adult males and females during dynamic tasks such as drop-jump landings (DJL). These differences are believed to be associated with the gender bias related to anterior cruciate ligament (ACL) injuries. Little research has been conducted to investigate lower extremity biomechanics of youth athletes in a similar manner to determine if these differences are present in a prepubescent population. Our objective was to assess sex differences in lower extremity kinetics during a DJL in a prepubescent athletic population. Our a priori hypothesis was that there would be no differences between sexes.

Methods: A cohort design study was conducted in a motion analysis laboratory. Sixteen healthy, physically active subjects volunteered for this study (9 males, age=9.6±1.5 years, height=1.5±.1 m, mass=34.6 ± 6.1 kg; 7 females, age= 10.6±0.8 years, height=1.5±.1 m, mass=35.1±7.7 kg). All subjects were prepubescent according to the Pubertal Maturation Observation Scale. Retroreflective markers were attached to the subject in accordance with the Vicon lower extremity marker set. Subjects performed 5 DJLs from a 40 cm box. They were instructed to step off the box with their dominant leg and land on 2 feet with only their dominant foot contacting a force plate. Immediately after landing subjects performed a maximal vertical jump. Kinetic data were recorded using a force plate synchronized with a 10-camera motion analysis system and data were analyzed during the stance phase of the DJL. The mean of peak external joint moments for hip extension, hip adduction, hip internal rotation, knee extension, knee abduction and knee internal rotation were calculated from all 5 trials. Statistical analysis consisted of 6 independent t-tests comparing the sexes.

Results: Females had significantly greater joint moments than males for hip extension (f=2.52±.95 Nm/kg, m=1.01± .30 Nm/kg, P<.001), hip adduction (f=.87±.54 Nm/kg, m= .44±.2 Nm/kg, P=.04), hip internal rotation (f= .35±.25 Nm/kg, m=07±.02 Nm/kg, P=.005) and knee internal rotation (f= .26±.24 Nm/kg, m=.08±.03 Nm/kg, P=.05). There were no significant differences in peak joint moments between the sexes for knee extension (f=.75±.48 Nm/kg, m=.48±.12 Nm/kg, P=.13) or knee abduction (f=.31±.19 Nm/kg, m=.19±.12 Nm/kg, P=.13).

Discussion: Contrary to our hypothesis, prepubescent females exhibited greater joint moments at the hip and knee during a DJL than males of the same maturation level. The most profound result was shown where females exhibited a 2.5 fold increase in peak hip extension compared to males. This finding is indicative of the female subject's decreased ability to control eccentric loading of the hip during the initial landing phase of the drop-jump. Research suggests that frontal plane hip moments are linked with trunk position and balance control. Females may be producing greater hip adduction and internal rotation moments due to insufficient activity of the gluteus medius muscle causing a lateral shift in the trunk center of mass.

Conclusions: The lower extremity kinetic profile leads us to believe that overall the prepubescent female subjects demonstrated an altered neuromuscular control pattern similar to those reported to be linked with non-contact ACL injury in adolescent and young adult research subjects. This finding may indicate that neuromuscular training programs need to be targeted at an even younger population in order to minimize the amount of non-contact ACL injuries sustained by female athletes.

Abstract #7

Comparison of Lower Extremity Coordination and Variability During a Jump-Landing Between Sexes

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Introduction: Differences in movement coordination and variability between males and females may be a risk factor for ACL injury. Previous research has demonstrated that females have increased variability in their motion patterns when compared to males. However, this research has focused on the movement of a single body segment, with variability measured at discrete points in time. There is little research examining the coordination and variability between two body segments over an entire movement cycle, which may provide a more complete examination of potential ACL injury risk factors. The purpose of this study was to compare lower extremity coordination and variability in the sagittal and frontal plane between males and females during a jump-landing task.

Methods: Twelve females (age=20.00±1.04 years, height=1.71±0.05 m, mass=62.48±8.34 N) and twelve males (age=20.83±1.85 years, height=1.80±0.05 m, mass=77.05± 5.69 N) volunteered to participate in the study. All participants were healthy, recreationally-active, and had experience playing soccer, lacrosse, basketball, or volleyball. Participants performed 10 jump-landings while three-dimensional kinematics and kinetics were collected with an infrared camera motion analysis system and forceplate. Sagittal and frontal plane segment angles and velocities were calculated relative to the global reference system for the foot, shank, thigh and trunk. Relative phase plots (position v. velocity) were created for each segment during the jump-landings, and relative phase angles calculated. Continuous relative phase portraits for each segment pairing (foot-to-shank, shank-to-thigh, and thigh-to-trunk) and each plane of motion were created, and the mean absolute relative phase (MARP) and deviation phase (DP) derived. MARP and DP values were compared using independent t-tests

($\alpha \leq 0.05$). The continuous relative phase portraits and DP plots, ensemble averaged for males and females, were also compared.

Results: Females displayed greater DP values in the sagittal plane shank-to-thigh pair (Females=14.01±1.85, Males=12.01±2.07, t=-2.49, p=0.021), and the frontal plane thigh-to-trunk pair (Females=47.62±7.67, Males=38.93±8.46, t=-2.63, p=0.015). There were no other significant differences in DP or MARP values between sexes. Examination of the DP plots indicates that females demonstrated higher variability during the first 50% of the stance phase. There were no substantial differences in the pattern of the continuous relative phase portraits for any segment pair.

Discussion: Females demonstrated greater variability in some of their coordinative strategies during a jump-landing, as indicated by higher DP values in the sagittal plane shank-to-thigh pair, and frontal plane thigh-to-trunk pair. This increased variability may indicate that the organization of female's neuromuscular system is less stable, and that females are searching for a more stable attractor state during this task. Greater variability may also increase the likelihood of performing a task in a high-risk position, placing lower extremity structures like the ACL at risk of injury. However, males and females do not demonstrate any differences in coordination between body segments. This indicates that each sex responds in a similar way to the constraints of the jump-landing task. These results help extend our knowledge of the sex-related differences in movement variability over an entire movement cycle, and further support the hypothesis that variability may play a role in the gender disparity in ACL injury rates.

Conclusions: Females and males demonstrate similar coordination strategies during a jump-landing, but the variation in some segment pairs is greater in females. These differences in the organization of the neuromuscular system may partially explain the disparity in ACL injury rates between males and females.

Abstract #8

Gender Differences in Quadriceps and Hamstring Co-contraction Patterns are Associated with Knee Joint Loading

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Introduction: Gender differences in neuromuscular control of the lower extremity have been identified as a potential causative factor leading to the increased incidence of ACL injuries in female athletes. Females tend to land in greater knee valgus with higher abduction loads compared to males. As knee abduction loads increase ACL strain, the inability to minimize these loads may lead to ACL failure. The primary purpose of the current investigation was to examine quadriceps and hamstring muscle activation to determine if co-contraction of these muscle groups were associated with the peak external knee abduction moment (PKAM) in males and females.

Methods: Recreationally active females (N = 11; 24.0 ± 5.2 yrs; 162.8 ± 6.6 cm; 55.9 ± 7.3 kg) and males (N=10; 23.6 ± 3.8 yrs; 174.1 ± 7.0 cm, 67.9 ± 7.3 kg) completed three trials of a 100 cm forward hop, while kinematics, kinetics, and quadriceps and hamstring EMG were recorded. An index of medial and lateral quadriceps to hamstring (Q:H) co-contraction as well as the peak knee abduction moment were calculated and used in the ensuing statistical treatments. Regression analyses were performed to examine possible associations between medial Q:H co-contraction and PKAM in the following subgroups: males only, females only, and both genders. T-tests were employed to determine if the medial Q:H index differed from the lateral Q:H index in females and males and to examine if the mean peak external knee abduction moments differed between males and females.

Results: Females had larger lateral Q:H co-contraction ratio (0.36 ± 0.19) than medial Q:H co-contraction ratio (0.19 ± 0.05) (t_{10} = 2.69, P = 0.025). The medial Q:H co-contraction index accounted for a significant proportion of the variance in the peak knee abduction moment in females (R^2 = 0.410, b = .251, P = .041), but not for males (R^2 = 0.190, b = 0.119, P = 0.481; 1-β = .30; f^2= 0.235) or when both genders were considered simultaneously in the model (R^2 = 0.143, b = 0.147, P = 0.37, 1- β = .44; f^2 = .167). Females displayed larger abduction moments compared to males (Males = -0.183 ± 0.08; Females = -0.330 ± 0.22; P = 0.05)

Discussion: The observed muscle imbalance in females and its association to the PKAM supports the idea that women may utilize ineffective neuromuscular strategies when landing from a jump, which precipitates their heightened ACL injury risk. Further, females displayed significantly less medial Q:H co-contraction compared to lateral co-contraction. The relationship between the medial Q:H co-contraction index and the PKAM may be partially explained by the role that the medial thigh musculature plays in resisting abduction loads. As the females displayed low levels of medial activation their ability to resist valgus moments may be reduced.

Conclusions: Medial-to-lateral Q: H co-contraction appears to be unbalanced in females, which may limit their ability to resist abduction loads. As higher abduction loads increase strain on the ACL and have been shown to be associated with ACL injury risk; restoring medial-to-lateral Q:H co-contraction balance has the potential to assist in reducing the incidence of ACL injury.

Abstract #9

Gender Differences in Hip and Knee Neuromuscular Activity During a Single-Leg Landing

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Introduction: Anterior cruciate ligament (ACL) injuries represent a serious knee injury incurred by females. Researchers have identified a quadriceps dominance pattern as a contributing factor. Hip influences, such as poor neuromuscular control, also may contribute to ACL injury. The purpose of this study was to compare hip and knee neuromuscular activity between males and females. The first research hypothesis was that females would generate greater quadriceps and less hip abductor and external rotator EMG activity during a single-leg landing than males. The second hypothesis was that females would activate the quadriceps sooner than the hip abductors and external rotators during a single-leg landing than males.

Methods: Nine male (25.3±5.6 yr; 179.0±4.9 cm; 80.3±6.2 kg) and 9 female (24.2±1.9 yr; 164.0±4.9 cm; 58.3±6.9 kg) recreationally-active healthy subjects participated. EMG electrodes were placed on the gluteus maximus (GMax), gluteus medius (GM), and vastus medialis (VM). A foot switch was placed in the shoe. Subjects initially performed 2 maximum voluntary isometric contractions (MVIC) for each muscle to express data as a percent MVIC (% MVIC). Subjects performed 5 single-leg drop landings from a 30.5-cm high box. EMG data were amplified (×2000), band-pass filtered at 15-350 Hz, and sampled at 2000 Hz. Data were then root-mean-square smoothed over a 40-ms window and expressed as a % MVIC. Normalized data were divided into a pre-landing (200-ms before contact) and post-landing (250-ms after contact) phase. For each muscle, the mean EMG activity during each phase was averaged over the 5 trials and analyzed. GMax, GM, and VM onsets relative to initial foot contact also were determined. Onset timing differences were determined by subtracting the VM onset from the GMax and GM onsets, respectively. A negative difference represented delayed VM activation relative to the GMax and GM; a positive difference represented preactivation of the VM relative to the GMax and GM. Onset timing differences (GMax onset – VM onset and GM onset – VM onset) for the 5 trials were averaged and analyzed. Due to a small sample size, separate Mann-Whitney *U* tests were used to identify between-group differences.

Results: Subjects demonstrated similar muscle amplitudes during the pre-landing phase ($P>.05$). Females generated similar GMax (34.4±12.4% MVIC vs. 22.2±11.1% MVIC; $P=.07$) and GM (46.9±10.8% MVIC vs. 34.7±15.0% MVIC; $P=.06$) but significantly greater VM (86.9±55.5% MVIC vs. 40.2±18.5% MVIC; $P=.04$) amplitudes during the post-landing phase than males. Males demonstrated a greater delay in VM activation relative to the GMax (-106.8±102.2 ms vs. 14.9±129.3 ms; $P=.04$) and GM (−152.9±114.8 ms vs. −10.0±115.3 ms; $P=.02$) than females.

Discussion: These findings support a female quadriceps dominance pattern. Researchers have shown increased anterior tibial translation in response to excessive quadriceps activation, especially in a minimally-flexed knee position. Females also activated the VM relatively sooner than males. Together, these activity patterns may cause excessive anterior tibial shear and strain the ACL. Increased femoral internal rotation and adduction can impart a knee valgus force and also strain the ACL. The GMax and GM may control these motions. Although no significant gender differences were found in amplitudes, males demonstrated a significant delay in VM activation relative to the GMax and GM. Earlier hip activation might stabilize the hip better to control excessive knee valgus. Efficient hip muscle activation also might dampen forces imparted through the lower extremity. Therefore, the combination of quadriceps dominance and poor hip control might increase the risk of ACL injury in the female athlete.

Conclusion: These findings provide preliminary evidence of the interrelationship between hip and knee neuromuscular activity between males and females. Additional studies are needed to better understand the influence of these parameters on hip and knee kinematics.

Abstract #10

Gender Differences in Neuromuscular Control of The Hip: Implications for Acute Non-Contact Anterior Cruciate Ligament Injury

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Introduction: Hip muscle strength and activation strategies influence lower extremity mechanical loading patterns, potentially reducing forces through the knee. Although factors affecting hip position and neuromuscular control have been increasingly implicated in ACL injury etiology, research is limited on the effect of the proximal segment on lower extremity force attenuation. The purpose of this study was to determine if gender differences existed in hip muscle strength, activation and lower extremity kinetics on a landing and countermovement task.

Methods: A post-test only design was used in a controlled laboratory setting. Forty two healthy, NCAA Division I collegiate and club sport male and female athletes (21 males, 21.1 ± 1.7 years, height = 181.2 ± 8.9 cm, mass = 85.3 ± 21.3 kg; and 21 females, 19.7 ± 1.5 years, height = 171.1 ± 8.6 cm, mass = 65.2 ± 7.3 kg) participated in the study. Isometric strength and strength ratios for the hip extensors, flexors, abductors, adductors, and lateral and medial rotators were measured with a hand-held dynamometer. Participants then performed a two-legged takeoff jump-to-one-legged landing with countermovement jump to maximal height. Preparatory (150 ms) and reactive (250 ms) electromyography (EMG) area and EMG co-activation area were collected for the gluteus maximus, biceps femoris, gluteus medius, iliopsoas, rectus femoris and adductor longus, and peak vertical ground reaction force, anterior shear force and lower extremity rate of loading were calculated from force plate data collected on a one-legged standing broad jump-to-vertical jump maneuver. Hip strength was analyzed using Independent t-tests. EMG and kinetic variables were analyzed with multiple one-way MANOVAs.

Results: Independent t-tests revealed that males had 12% greater isometric hip flexor ($t = 2.1$, $p = .041$, males = 5.9 ± 1.3, females = 5.2 ± .7 N/kg). and 15% greater lateral rotator ($t = 2.5$, $p = .016$, males = 5.4 ± 1.4, females = 4.6 ± .6 N/kg) strength. A one-way MANOVA revealed that females had 12% greater gluteus maximus ($F = 7.7$, $p = .008$, females = 14.1 ± 1.8, males = 13.0 ± 1.9), rectus femoris ($F = .41$, $p = .050$, females = 15.2 ± 1.9, males = 13.5 ± 3.3), and combined co-agonist gluteus maximus and biceps femoris ($F = 13.7$, $p = .001$, females = 28.6 ± 2.7, males = 25.7 ± 2.6) EMG reactive area. No other significant gender differences were found.

Discussion: Controlling the downward vertical acceleration of the center of mass is important for knee joint stability. Greater gluteus maximus and rectus femoris EMG reactive area demonstrated by females may reflect an inefficient muscle activation strategy, potentially leading to earlier onset of fatigue and deterioration of landing technique due to hip and pelvis destabilization. Female weakness in hip flexor and lateral rotator muscles, may necessitate greater rectus femoris muscle activation after ground contact to effectively decelerate the rate of knee flexion and greater gluteus maximus activation to decelerate the rate of hip and trunk flexion and limit excessive medial femoral rotation.

Conclusions: Possibly due to specific muscle weakness, females appear to place greater reliance on reactive muscle activity to attenuate landing forces on a complex landing task with countermovement. This strategy may lead to early fatigue and predisposition to increased risk of acute non-contact injury.

Abstract #11

Transverse Plane Positioning of the Hip is Different Between Males and Females During a Sidestep Cut

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Introduction: There is ample evidence in the literature to support that females tend to perform functional activities with the hip positioned in more internally rotated position when compared to males. This has been identified as a possible risk factor in the greater incidence of ACL injuries in females as compared to males, as a more internally rotated hip may result in more valgus and rotary stress at the knee.

Methods: Twenty-four volunteers (12 males; height=177.9±7.5 cm; mass=83.8±17.6 kg, age=22.6±1.7 yrs and 12 females; height=165.6±5.7 cm; mass=61.6±6.3 kg, age=23.4±3.7 yrs) participated in this study. An 8-camera, 3-dimensional motion analysis system was used to assess the kinematics of the right hip and knee for each subject during a predetermined sidestep cutting maneuver. All subjects performed the sidestep cut with the right foot planted and cut at a 45° angle to the left. Kinematic variables examined at the hip and knee were joint angle at initial contact, peak joint angle, time-to-peak angle (TTP), and total joint angle change in 3 planes of motion. Individual T-tests were performed to identify differences between the sexes.

Results: At initial contact with the force plate, males were in a position of hip internal rotation while females were in a position that was nearly neutral in rotation (males: 16.7 ± 12.0°; females: −0.01 ± 16.2°, effect size = 1.2, P = .009). Note that internal rotation is designated positive, while external rotation is designated as negative. Total hip rotation angle change and time to peak rotation angle were not significantly different between the sexes. No significant differences were seen between males and females for any variables in the sagittal or frontal planes.

Discussion: Females began their sidestep cut in a more externally rotated position when compared to males. Males tended to be in a position of internal rotation at initial contact, while females were in a position of neutral-to-external rotation. During a sidestep cutting maneuver, leg position at initial contact may be important; an internally rotated femur is more "unwound" at the knee as the subject cuts to the left. An externally rotated position of the femur may increase the rotary forces at the knee as the individual continues through the cut. Interestingly, the transverse plane total angle change and time-to-peak angle at the hip were not significantly different between the sexes.

Conclusions: Based on previous evidence, we expected that females would perform this task in a more internally rotated position compared to males. This was not the case during the performance of this sidestep cut. The results indicate that limb positioning at initial contact may be important. Future research might examine the internal and external moments during these maneuvers and determine the contributing kinetic factors of performing this functional task differently.

FATIGUE AND PERTURBATION STUDIES IN LANDING AND CUTTING

Abstract #12

Gender Differences in Time-Frequency EMG Analysis of Unanticipated Cutting Maneuvers

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Introduction: Many researchers investigating the gender bias with regards to noncontact anterior cruciate ligament (ACL) injuries use the electromyography (EMG) signal but most of them examine the signal's amplitude and timing information. Few researchers assess its time-frequency components, which can provide valuable information related to motor unit recruitment strategies. The purpose of this study is to compare the time-frequency characteristics of the EMG signal, as well as the three-dimensional (3D) knee kinematics of female and male elite soccer players performing an unanticipated cutting maneuver.

Methods: Fifteen female (F) (age: 21.1 ± 3.6 years; soccer experience: 13.7 ± 4.3 years) and 15 male (M) (age: 22.9 ± 3.7 years; soccer experience: 15.8 ± 3.3 years) elite soccer players performed several cutting maneuvers during which EMG of eight muscles of the right leg and 3D kinematics of the right knee were recorded. To create an unanticipated condition, the participants executed one of three tasks, which were signaled to them with an illuminated target board. The knee kinematic values at initial ground contact (IC), as well as the peak values were obtained. By means of a custom MATLAB® program, the short time mean frequency (STMNF) and the total intensity (TI) were obtained using non-linearly scaled wavelets. TI represents a close approximation of the EMG signal's power, which is proportional to the amplitude squared. One-way ANOVAs were used to determine if a significant difference exists between genders with regards to the 3D knee kinematic variables and the EMG variables.

Results: Male participants generally executed the stance phase of the unanticipated cutting maneuver with a quadriceps activation of higher frequency components. These gender differences were also found at IC for the vastus lateralis (VL) (F: 79.00 ± 19.97 Hz; M: 99.34 ± 21.08 Hz; p=0.011), vastus medialis (VM) (F: 88.83 ± 21.38 Hz; M: 112.78 ± 25.97 Hz; p=0.010) and biceps femoris (BF) (F: 61.75 ± 24.14 Hz; M: 89.20 ± 41.12 Hz; p=0.034). The peak TI of the signal occurred earlier in time for the BF in women (F: −12.35 ± 6.64%; M: −7.12 ± 5.54%; p=0.026).Timing variables are reported as a percentage of the cutting cycle in relation to IC. Furthermore, the female participants performed the cutting task with greater knee abduction angles at IC (F: −2.98 ± 5.10°; M: 1.28 ± 5.10°; p=0.050) and greater peak knee abduction angles (F: −15.31 ± 8.84°; M: −5.26 ± 11.28°; p=0.011).

Discussion: These higher mean frequencies might indicate that a greater number of, and/or higher frequency contributing, motor units are being recruited in the male quadriceps. Most interestingly, the reduction in median frequency components of the lateral hamstrings detected in the female athletes at, and close in time to, IC was not observed in the male group, although both group displayed a reduction in total intensity of the signal during that portion of the maneuver. Hence, it can be suggested that the women experienced a decrease in the number of active high frequency contributing motor units in the BF, whereas the men, who maintained high STMNF components, may have experienced a small reduction in the number of active motor units with slower constituent firing rates. Given that it was found that soccer players adopted generalized co-contraction strategies during the unanticipated cutting task to achieve knee stabilization, a reduction in higher frequency components of the BF's motor units could reduce the effectiveness of this knee stabilizing strategy, thus leaving the ACL at a higher risk of injury. Furthermore, we speculate that the female athletes generated greater ACL strain than their male counterparts due to the execution of the unanticipated cutting maneuver with greater knee abduction angles, which may place them at a greater risk of noncontact ACL injuries, especially when combined with an internally rotated knee.

Conclusions: Female athletes adopted a different motor unit recruitment strategy that was particularly evident at, and near, initial ground contact, resulting in lower frequency components in the EMG signal of the lateral hamstring. This strategy may play a role in explaining the gender bias in ACL injury rates. Gender differences in knee kinematics were also observed, exposing the female ACL to higher strain, which may be the result of differences in neuromuscular strategies to stabilize the knee joint.

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Table 1. Lower extremity kinematics and kinetics during unanticipated single leg landings (mean ±SD)

	IC Hip Flx	IC Hip Add	IC Hip Int Rot	Peak Knee Int Rot Moment
AN	29.66±8.54	−1.88±7.43	9.16±9.15	−0.09±0.08
UN1	24.06±8.74*	−5.71±7.42*	10.76±8.33	−0.12±0.08
UN2	23.99±8.42*	−5.90±6.95*	12.44±7.57	−0.15±0.12*
UN3	23.35±8.89*	−5.44±6.81*	12.97±7.52*	−0.17±0.12*

*denotes statistical significance ($p<0.05$) from AN condition.

Abstract #13

An Unanticipated Stimulus Alters Lower Limb Mechanics During Single-Leg Landing

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Introduction: Unanticipated landings induce substantial and potentially high risk alterations in stance phase lower limb mechanics, resulting in their increased use in the assessment of non-contact ACL injury risk. Currently, the extent to which the timing of the unanticipated stimuli impacts the movement response remains largely unclear. Insights into this relationship may afford improved screening and prevention modalities that more appropriately represent the inherently random movements consistent within sports where ACL injuries proliferate. The purpose of this study therefore, was to examine the effects of temporal variations in unanticipated pre-landing stimuli on resultant lower limb mechanics.

Methods: Twenty six subjects (13 male 20.8 ± 1.6 yrs and 13 female 20.8 ± 1.0 yrs) performed four randomly ordered series of ten successful anticipated (AN) or unanticipated (UN1, UN2 or UN3) single leg landings, off both the left and right legs. For the three UN landings, a random light stimulus was presented 600 ms (UN1), 500 ms (UN2) or 400 ms (UN3) prior to ground contact, which governed the required landing foot and resultant jump direction. For AN trials, the stimulus was presented before initiation of the movement. Leg dominance was assessed as the leg the subject preferred to a kick a ball the furthest. Mean subject-based initial contact (IC) and peak stance (0%-50%) phase3D lower limb joint kinematics and normalized (wt × ht) kinetics were calculated for all AN and UN conditions and subsequently submitted to a repeated-measures ANOVA to determine the main effects of decision.

Results: Subjects demonstrated significantly more ($p<0.001$) IC hip flexion and ($p<0.05$) IC hip adduction during AN compared to all three UN conditions, and less ($p<0.05$) IC hip internal rotation compared to the UN3 condition (Table 1). Peak stance phase knee internal rotation moments were significantly less ($p<0.05$) during AN compared to UN2 and UN3 conditions (Table 1).

Discussion: Our results suggest that hip kinematics and knee kinetics at landing are different between unanticipated and anticipated landings; however, the timing of the unanticipated stimuli appears to contribute minimally to the changes observed in these patterns. While expanding the range over which stimuli are introduced may indeed elicit more substantial biomechanical variations during the landing phase, it unlikely reflects a range within which successful movement execution remains possible. Hence, we are confident current observations adequately reflect the random variations in timing experienced within realistic sports participation. Within the random sports environment for example, an athlete may demonstrate a substantial landing limb preference, precipitating a bilateral mechanical imbalance. Such an imbalance may be problematic if a random external stimulus necessitates landing on the non-preferred, less frequently used limb. Similar discrepancies in training and exposure to random movement environments may also explain concomitant sex-based differences in single leg landing mechanics. Further research is required, however, to test this tenet explicitly.

Conclusion: Lower limb mechanical differences demonstrated between anticipated and unanticipated landing maneuvers suggests inclusion of the later within current ACL injury screening and prevention methods should be considered. The relative timing of unanticipated stimuli presented within these movements, however, appears less critical. Further work now appears necessary to investigate the potential for unanticipated movement drills that cater to underlying biomechanical variations across sex or limb conditions.

Abstract #14

The Effect of a Rotational In-Flight Perturbation on Landing Biomechanics

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Introduction: Perturbations have been implicated as a mechanism for ACL injury. One type of perturbation athletes encounter are in-flight perturbations. Although these events are common and have been associated with the occurrence of ACL injuries, the effects of these events on drop landing biomechanics are not known at this time. Therefore, the purpose of this study was to determine the effect of a rotational in-flight perturbation on landing biomechanics.

Methods: Twelve college-aged female (21.2±1.5 yr, 64.6±7.9 kg, 171.9±5.5 cm) soccer and basketball athletes (participation: soccer = 11.6±5.0 yr, basketball 9.2±7.1 yr) performed double-leg drop landings 0.6 m from the ground with (PERT) and without (CON) in-flight perturbations being applied. Three-dimensional ground reaction forces (1200 Hz) and lower extremity joint kinematics (240 Hz) and kinetics were analyzed for the right limb using paired t-tests ($\alpha = 0.05$).

Results: Compared to CON landings, peak vertical ground reaction force (VGRF) was decreased during PERT landings ($p=0.05$, 24.7±7.2 N/kg and 23.5±6.7 N/kg, respectively). There were no significant differences for lower extremity joint kinematic or kinetic magnitudes between landing conditions. The relative times to peak hip ($p=<0.01$, 84.9±11.3% and 78.6±13.4%, respectively) and knee flexion ($p=0.03$, 90.9±7.8% and 85.1±12.6%, respectively) occurred later and relative time to the peak ankle plantarflexor moment ($p=0.01$, 3.7±2.2% and 5.6±2.3%, respectively) occurred earlier during the PERT compared to the CON condition.

Discussion: Decreased peak VGRF during PERT landings was diametrically opposite to the original prediction. This may have occurred due to a longer time to apply force to the ground, as evidenced by later relative times of knee and hip flexion during PERT landings. The decreased VGRF during PERT landings could also be interpreted as the participants altering their landing strategy due to anticipation of the perturbation. The lack of significant differences found between conditions led the researchers to qualitatively analyze the data at the individual participant level. There appeared to be support for the prevalence of individual variation in landing strategies. These individual variations were present in both knee joint kinematics and kinetics. The effect of these variations on ACL injury incidence is difficult to discern at this time. However, the individual variation demonstrated by the participants of this study supports that strategies differ among and within participants and these variations in landing strategy could predispose a certain set of individuals to an increased risk of ACL injury. The low magnitude of the in-flight perturbation created in this study may represent typical perturbations encountered in the real world but are insufficient to cause injury. A limitation is that performing a perturbation task could result in a participant developing anticipatory strategies different than would emerge during a sport situation.

Conclusions: In-flight perturbations are common during sports participation and low magnitude rotational perturbations appear to influence the temporal pattern of landing biomechanics and the individual participant responses to perturbations. Future research will focus on determining if differences exist between males and females and the effect of the magnitude of an in-flight perturbation on landing biomechanics.

Abstract #15

Footwear Does Not Alter Muscle Response Time Following a Weight Bearing Rotary Perturbation

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Introduction: The Lower Extremity Perturbation Device (LEPD) is a research tool that is capable of inducing a sudden either femoral medial or lateral rotation on a fixed tibia in a weight-bearing posture. Investigators have used this tool to study the muscular responses times (MRTs) of athletes in single leg stance. Most of the work using the LEPD however, has been conducted without shoes. As the majority of athletic activity is performed with shoes it has been questioned whether or not the use of shoes during testing with this tool would alter MRTs. The purpose of this study was therefore to compare the MRT of select lower extremity muscles following a weight bearing rotary perturbation in single leg stance with and without shoes. The null hypothesis was no differences in MRT would be evident between conditions.

Methods: Ten recreationally active female subjects (height: 165.6 cm ± 6.5, mass: 65.5 kg ± 8.7, age: 22.6 years ± 1.1) volunteered to participate. Using the LEPD and standardized positioning, all participants were subjected to 20 perturbations (10 medial; 10 lateral) performed in a random order on the dominant lower extremity in no shoe and standardized shoe conditions. An electrogoniometer was used to standardize knee flexion angle at 20° while surface electrodes interfaced with a telemetery electromyographic (EMG) unit were placed over the medial and lateral quadriceps, hamstrings and gastrocnemius muscles. All hardware including a cable from the LEPD release mechanism were interfaced with a personal computer and commercially available software acquisition and analysis system. Data were collected synchronously using a trigger sweep initiated by release of the cable from the LEPD. The first 5 trials to meet the inclusion criteria were signal averaged. Latency of each muscle was then derived using previously published methods. Separate (medial & lateral) repeated measures ANOVAs compared the influence of shoewear (2 levels) on MRTs (6 levels). Alpha levels were set a-priori at $P < 0.05$.

Results: Significant differences in MRTs were not apparent for either the medial ($P = 0.37$) or lateral ($P = 0.71$) perturbation between conditions. For the medial rotation perturbation, MRTs averaged 77.3 milliseconds (ms) for the shoe condition compared to 74.5 ms for the no shoe condition. Similarly, for the lateral rotation perturbation, MRTs averaged 79.2 ms for the shoe condition compared to 77.1 ms for the no shoe condition. While a main effect for muscle was evident for both medial and lateral perturbations ($P < 0.001$) a muscle by shoe interaction was not present for either the medial ($P = 0.89$) or lateral ($P = 0.10$) perturbation.

Discussion: These data suggest MRTs of the medial and lateral quadriceps, hamstrings and gastrocnemius do not vary when tested with or without shoes in response to a sudden rotary perturbation in single leg stance with the knee flexed to 20°. While our total subject enrollment was small, effect sizes were also small indicating the addition of a reasonable number of subjects would not have changed the outcome of this work. So while differences in neuromuscular activity have been detected in subjects while running when shoe and no shoe conditions have been compared, these discrepancies were not evident when the LEPD was used as a model.

Conclusions: MRTs of the tested muscles for the above procedures are not significantly different between shoe and no shoe conditions in recreational female athletes. These data indicate LEPD testing may be done with or without shoes and comparisons between works are permissible as response times are unaffected.

Abstract #16

Isolated Quadriceps and Hamstrings Fatigue Alters Hip and Knee Mechanics

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Introduction: Neuromuscular fatigue exacerbates abnormal landing strategies, which may increase non-contact anterior cruciate ligament (ACL) injury risk. However, the precise impact of simultaneous quadriceps and hamstring (QH) muscle fatigue, whose synergistic actions are central to a successful landing, is unclear. Elucidating the impact of QH fatigue on lower limb landing mechanics may facilitate more effective fatigue-resistance training and prevention regimens. The purpose of this study therefore, was to examine the effects of QH fatigue on lower extremity mechanics during a single-leg, dynamic landing task. A secondary purpose was to determine if sex differences in lower extremity mechanics exist following QH fatigue.

Methods: Thirteen healthy male (height 1.8±0.1 m; mass 76.0±8.9 kg) and twelve healthy female (height 1.7±0.1 m; mass 58.3±7.7 kg) volunteers performed three single-leg forward hops onto a force platform before and after substantial QH fatigue. Fatigue was induced through sets of alternating QH concentric contractions on an isokinetic dynamometer until subjects performed the first five repetitions of a given set at 50% below their QH peak torque. Three dimensional hip and knee kinematics and normalized kinetics were quantified for pre- and post-fatigue landing trials, from which mean subject-based values were determined for initial contact (IC) and peak vertical ground reaction force (vGRF). Repeated measures mixed model two-way ANOVAs were used to test for the main effects of, and possible interactions between, sex and fatigue.

Results: Fatigue produced significant increases in IC hip internal rotation (pre-fatigue 0.28±7.42°, post-fatigue 3.5±7.0°, $P=0.021$), knee extension (pre-fatigue 13.38±5.36°, post-fatigue 7.42±6.31°, $P=0.001$), and knee external rotation (ER) angles (pre-fatigue 0.29±2.89°, post-fatigue -2.38±5.56°,

$P=0.04$). Fatigue-induced increases in knee extension (pre-fatigue 25.40±8.76°, post-fatigue 19.14±8.82°, $P=0.002$) and ER (pre-fatigue 0.27±3.37°, post-fatigue -2.34±5.62°, $P=0.02$) angles were also evident at peak vGRF. Smaller peak vGRF knee flexion (pre-fatigue 0.8±0.63 Nm, post-fatigue 0.29±0.38 Nm, $P=0.002$) and ER (pre-fatigue 0.14±0.12 Nm, post-fatigue 0.07±0.11 Nm, $P=0.04$) moments were evident post-fatigue. No sex × fatigue effects were found ($P>0.05$).

Discussion: Landing in a more erect posture following fatigue suggests subjects may demonstrate increased knee stiffness in order to prevent knee collapse upon landing. Fatigue-induced increases in hip internal rotation may further represent a postural adaptation to the altered knee control that was apparent. As hip internal rotation, knee extension, and knee ER have been implicated in the ACL injury mechanism, and these postures increased following fatigue, the need for fatigue-resistance training appears a warranted addition to ACL prevention programs. The lack of sex differences in lower extremity mechanics post-fatigue might be related to a concomitant lack of sex differences in QH strength (normalized to body mass) post-fatigue.

Conclusion: Isolated QH fatigue results in altered hip and knee mechanics that may increase risk of ACL injury in both sexes. These findings suggest the need for fatigue-resistance training to target key synergistic muscle actions within prevention programs.

Abstract #17

Fatigue-Induced Changes in Central Control Increases Non-Contact ACL Injury Risk in Females

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Introduction: Dynamic sports landing execution in a combined fatigued and unanticipated state is a proposed worst case scenario for non-contact ACL injury risk, particularly in females. To date, however, the extent to which this phenomenon stems from a compromise in central versus peripheral mechanisms remains unclear. Elucidating the links between fatigue and these mechanisms, and subsequent risk of ACL injury is crucial to prevention strategies that can successfully cater to the inherently random nature of sports. Considering this fact, therefore, the purpose of the current study was to determine the impact of fatigue on the central control of dynamic lower limb landing mechanics.

Methods: Eighteen female athletes (19.8 ± 1.2 yrs) performed anticipated (AT) and unanticipated (UT) single leg landing tasks both before and during exposure to a generalized fatigue protocol. Jump direction was determined by random light stimuli activated prior to or during the pre landing phase of AT and UT respectively. For fatigue trials, subjects performed three single leg squats immediately followed by a randomly ordered landing, with this sequence repeated until squats were no longer possible. Subject- based initial contact (IC) and peak stance (0%-50%) lower limb joint kinematics and normalized (wt × ht) peak stance external kinetics were calculated across pre-fatigue trials, and for trials denoting 25%, 50%, 75% and 100% maximal fatigue. These data were submitted to a 3-way ANOVA to test for the main effects of and potential interactions between decision (AT and UT), limb (fatigued and non-fatigued) and fatigue level.

Results: UT promoted significant ($p<0.05$) increases in IC hip extension and internal rotation and knee flexion angles, peak stance knee abduction and internal rotation angles and moments and peak stance knee flexion moment. IC knee extension, peak knee abduction angle, and peak knee flexion and abduction moments all significantly ($p<0.05$) increased as fatigue progressed. Further, fatigue induced increases in peak knee abduction motions and loads were more pronounced ($p<0.05$) during UT compared to AT. Changes in joint mechanics due to decision and/or fatigue level conditions were similarly evident in both the fatigued and non-fatigued limb (Figure 1).

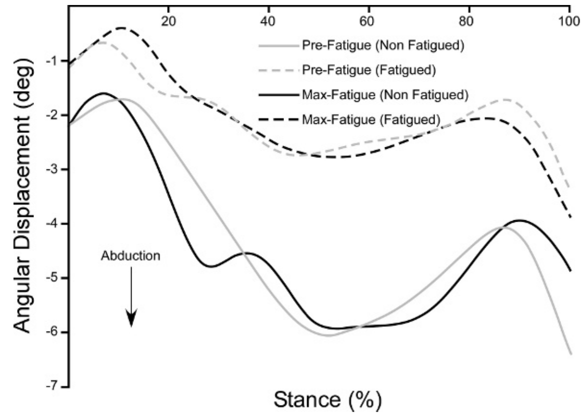

Figure 1. Comparison of fatigued and non-fatigued limb stance phase knee abduction during UT.

Discussion: Current results further support the notion that the combination of fatigue and decision making, factors both synonymous with realistic sports participation, presents as a likely high risk scenario in terms of ACL. The integration of combined fatiguing and decision making drills within current screening and prevention modalities thus appears well warranted. The substantial mechanical adaptations observed in the non-fatigued limb also strongly suggest high risk resultant movement strategies stem from fatigue induced degradation in the central processing and/or control pathways. Prevention strategies would thus benefit from targeting the interaction between fatigue and central (spinal and supraspinal) mechanisms within the training paradigm.

Conclusion: Fatigue induced changes in lower limb landing mechanics stem from substantial degradation in central processing and/or control pathways. These changes, and hence the potential for non-contact ACL injury are exacerbated during unanticipated movements, where significant demands on spinal and supraspinal mechanisms already exist. Current prevention methods would benefit from strategies geared towards the training and enhancement of these mechanisms, particularly in the presence of fatigue. Ongoing work should now attempt to decipher the precise manifestations of fatigue within the central control of extreme landing postures.

Abstract #18

The Effects of Fatigue and Recovery on Knee Kinetics and Kinematics During Side-Step Cutting

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Introduction: Changes in knee mechanics immediately following a fatiguing bout of exercise are thought to place an individual at greater risk for ACL injury. However, the recovery time required to restore normal knee kinetics and kinematics following fatigue has not been established. The purpose of this study was to examine knee mechanics during side-step cutting immediately following a fatigue protocol and after 20 and 40 minutes of rest.

Methods: Knee kinematics (8-camera VICON system) and kinetics (AMTI force platform) of 15 female recreational athletes were recorded during a side-step cutting task. Data were obtained at 4 different time points: 1) prior to a fatigue protocol; 2) immediately following the fatigue protocol; 3) 20 minutes after the fatigue protocol; and 4) 40 minutes after the fatigue protocol. Peak knee joint angles and knee joint moments in the sagittal, frontal, and transverse planes were identified during the deceleration phase of the cutting task. One-way ANOVAs with repeated measures were used to compare the variables of interest among the four time points. In cases where an ANOVA was significant, post-hoc testing was performed using paired-t tests. All significance levels were set at $p \leq 0.05$.

Results: Peak knee adductor (valgus) moments post-fatigue were significantly greater than pre-fatigue values (1.48±0.7 vs. 1.19±0.54 Nm/Kg; $p=0.002$) and remained elevated at 20 minutes (1.45±0.82 Nm/Kg; $p=0.03$) and 40 minutes post-fatigue (1.43±0.75 Nm/Kg; $p=0.05$). Peak knee internal rotation angles post-fatigue also were significantly greater than the pre-fatigue values (9.7±6.4 vs. 4.8±5.3 degrees; $p<0.001$) and remained elevated 20 minutes (7.2±6.3 degrees; $p=0.02$) and 40 minutes post-fatigue (6.8±5.8 degrees; $p=0.04$). Peak knee valgus angles immediately following the fatigue protocol were significantly greater than pre-fatigue (6.9±3.7 vs. 4.5±3 degrees; $p=0.008$) but returned to pre-fatigue levels following 20 minutes of rest. The fatigue protocol had no influence on any other of the variables examined.

Discussion: Our data support the premise that fatigue related changes in knee kinematics and kinetics may place an individual at a greater risk for ACL injury. Increased knee internal rotation may increase the load on the ACL as it is a primary restraint for this motion. In addition, increased external knee valgus moments have been associated with ACL injury. Peak internal rotation angle and external knee valgus moments were not restored to pre-fatigue values after 40 minutes of rest, indicating that the typical halftime period (e.g., 15–20 minutes) during sports competitions may not be sufficient for restoring normal knee mechanics following fatigue.

Conclusion: Fatigue resulted in changes in knee mechanics that are thought to be associated with ACL injury. Forty minutes of recovery was not sufficient in restoring knee mechanics to pre-fatigue levels.

Note: This study was presented in the XXI International Society of Biomechanics (Taiwan, July 2007).

ANATOMICAL AND HORMONAL FACTORS

Abstract #19

Comparison of Cyclic Variations in Anterior Knee Laxity, Genu Recurvatum and General Joint Laxity Across the Female Menstrual Cycle

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Introduction: Greater anterior knee laxity (AKL), genu recurvatum (GR) and general joint laxity (GJL) have each been implicated as risk factors for ACL injury. In previous work, increases in AKL have been observed in females from their early follicular to early luteal phases, with the magnitude of change varying among women depending on their hormone profiles.[1] Whether cyclic changes in AKL are accompanied by cyclic changes in genu recurvatum (GR) and general joint laxity (GJL) is unknown. We compared males, female non-responders (those who do not experience marked changes in AKL across their cycle) and female responders (those who experience marked changes in AKL across their cycle) on clinical measures of genu recurvatum and general joint laxity.

Methods: Thirteen males (23.6±2.9 yrs, 178.8±11.2 cm, 83.9±11.3 kg) and 29 normally menstruating females (22.0±3.1 yrs, 163.3±6.1 cm, 59.3±6.3 kg) who were recreationally active with no history of knee injury were prescreened to insure a distribution of baseline AKL values that broadly fell above and below the population mean (range 3–12 mm). For two consecutive months, AKL, GR and GJL and serum samples were collected from females in the morning hours for 6 days following the onset of menses, and 8 days following a positive ovulation test to determine the specific days in the early follicular and luteal phases when knee laxity values were at their minimum and maximum values, respectively. AKL was measured in millimeters (mm) using a standard knee arthrometer, supine active GR was measured in degrees (°) using a goniometer, and GJL was measured as the total score (0–9) using the Beighton and Horan joint mobility index. Using data obtained from their second cycle, minimum and maximum AKL values were identified in the early follicular (T_{Min}) and luteal phases (T_{Max}) respectively for each female. Females were then grouped as hormone responders (FR) or non-responders (FNR) if their change in AKL ($T_{Max} - T_{Min}$) was greater or less than 5 SD of the day to day measurement error (± 1.5 mm). Using this criteria 14 females were identified as FNR (AKL change = 0.88±0.33 mm) and 15 females were identified as FR (AKL change = 1.95±0.41 mm). Males were measured on two occasions, with the time between tests matched to a female with similar AKL values. Separate 2 (Time) × 3 (group) repeated measures ANOVA compared males, FR and FNR on AKL, GR and GJL as measured at T_{Min} and T_{Max}.

Results: A group by time interaction ($P < .001$) revealed no group differences in AKL at T_{Min} (Males=6.9±2.3 mm, FNR=5.5±1.3 mm, FR=6.6±2.54 mm; $P = .168$), but greater values in FR (8.5±2.7 mm) than FNR (6.3±1.3 mm) but not males (6.9±2.2 mm) at T_{Max} ($P = .022$). A similar group by time interaction was noted for GR ($P < .001$). While males had a decrease in GR from T_{Min} to T_{Max} (−0.38±0.47°), both FNR (0.53±0.89°) and FR (1.27±1.39°) had significant but disproportionate increases from T_{Min} to T_{Max}. This resulted in greater GR in FR (6.0±4.2°) than FNR (2.3±1.8°) at T_{Max} ($P = .023$). Further, a main effect for group ($P = .052$) revealed that FR (5.4±4.2°) had on average 3.3° greater GR than FNR (2.1±1.7°) ($P = .047$) but only 1.6° greater GR than males (3.8±4.0°) ($P = .708$). While there was no group by time interaction for GJL ($P = .375$), a main effect for group ($P = .018$) revealed higher GJL scores in FR (3.0±2.1) compared to FNR (1.4±1.1, $P = .028$) and males (1.5±1.5, $P = .061$).

Discussion: Females who experience greater changes in AKL from the early follicular to early luteal phases (FR) experienced greater increases in GR when compared to FNR and males, and also had greater overall GR and GJL than FNR. Hence, these females appear to not only experience acute increases in joint laxity across their cycle, but also appear to have baseline laxity profiles that are on average greater than females who do not experience substantial changes in joint laxity across their cycle.

Conclusions: Cyclic increases in AKL are accompanied by cyclic increases in GR. Work is ongoing to determine whether these clinical laxity differences (both in absolute baseline values and in cyclic variations) have a significant impact on knee joint neuromechanics during weight bearing activity.

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From the Transactions of the 54th Annual Meeting of the Orthopaedic Research Society, March 2–5, 2008, San Francisco, CA. Paper #0190. A Comparison of Cyclic Variations in

Anterior Knee Laxity, Genu Recurvatum and General Joint Laxity Across the Female Menstrual Cycle. Shultz, Sandra J.; Nguyen, Anh-Dung; Perrin, David H.

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Abstract #20

ACL-Injured Subjects Have Smaller ACLs than Matched Controls: An MRI Study

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Introduction: Identifying structural and material properties of the ACL has been an intense area of research, and studies have determined that ACL volume, cross-sectional area and material properties are correlated to gender, height, age, and weight[1,2,3]. However, no direct link between ACL size and injury has been investigated, as previous comparative studies on ACL morphology have all focused on gender comparisons. A narrower ACL *in vivo* could identify a predisposition for non-contact ACL injury for males as well as females. This study tested the hypothesis that a smaller ACL leads to ACL injury, controlling for gender, height, age, and weight, by comparing the ACL volumes of the contralateral knees of individuals who previously experienced a non-contact ACL injury to control subjects matched for gender, height, age, and weight.

Methods: 54 subjects (34 male) participated in this study after providing IRB-approved informed consent, divided equally into 2 groups. The injured group consisted of the healthy, contralateral knees of individuals who had experienced a non-contact ACL injury. The control group consisted of knees of uninjured subjects matched for gender, height, age, and weight to the injured group. MR images were taken of a single knee for the control subjects and of the healthy knee of the injured group. The ACL of each subject was segmented from MR images (1.5T, sagittal 3D-SPGR, voxel size 0.55 mm × 0.55 mm × 1.5 mm) using standard software (MIPAV, v2.7.45)[4] under the guidance of an experienced orthopaedic surgeon. The volume of each ACL was calculated by MIPAV from the manually drawn contours. The volumes were compared between groups using a paired one-tailed Student *t*-test ($\alpha = 0.05$). For comparison to previous studies, the correlation of ACL volume to height was also calculated.

Results: The average ACL volume for the injured group was 1955 mm^3, significantly smaller than the average volume for the control group (2117 mm^3) ($p=0.037$), with 16 of the 27 injured subjects having smaller ACLs than their matched control (Figure 2). The correlation of volume to height across all subjects was 0.57.

Discussion: The results of this study show that patients who have suffered a non-contact ACL injury have a significantly smaller ACL volume in their contralateral knee than matched controls. This result is consistent with a smaller ACL being weaker, and therefore at greater risk of injury. Similar results have been found when comparing male vs. female ACL volume[2], with a larger difference due to gender than what we have observed between injured and control subjects. However, the previously observed difference in ACL volume between males and females may have been largely due to stature, as males and females were of significantly different heights. Our observed correlation between body height and ACL volume was also consistent with the previously published value of 0.58[2].

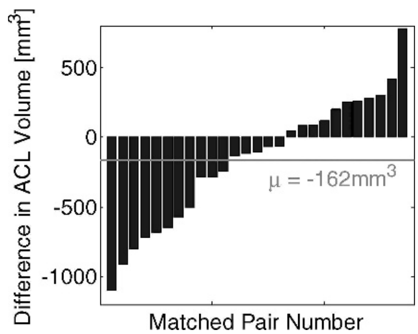

Figure 2. Distribution of ACL volume difference for pairs of non-injured and non-contact injured subjects.

One major limitation of this technique was the use of manual segmentation of the ACL from MRI. The ACL can often be difficult to distinguish from surrounding tissue, possibly leading to errors in the subsequently calculated volume. Another limitation is the use of the contralateral ACL to represent the volume of the ruptured ACL, since the side-to-side variability in ACL volume in healthy subjects remains unknown.

Conclusion: ACL volume may be a risk factor for non-contact ACL rupture, in conjunction with the many other potential risk factors that have previously been identified. A future comprehensive study that attempts to create screening metrics based on as many of these factors as possible, including ACL volume, may prove to be the most effective in identifying at-risk individuals.

From the Transactions of the 54th Annual Meeting of the Orthopaedic Research Society, March 2-5, 2008, San Francisco, CA. Paper #1268. ACL-Injured Subjects Have Smaller ACLs Than Matching Controls: An MRI Study. Zelman, Eric A.; Chaudhari, Ajit M.; Flanigan, David C.; Kaeding, Christopher C.; Jia, Guang; Knopp, Michael V.

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Abstract #21

Differences in Lower Extremity Anatomy and Posture Characteristics in Males and Females Between Maturation Groups

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Introduction: Sex differences in lower extremity anatomy and posture characteristics are cited as potential risk factors for the increase prevalence of knee injury in females. In the adult population, sex differences have been identified in the anatomy and posture of the hips and knees, with females having greater hip internal rotation, knee valgus and recurvatum. While the reasons contributing to these sex differences are not entirely known, they are thought to be developmental in nature, with postural differences emerging during growth and development. Our purpose was to cross sectionally examine sex differences in a variety of lower extremity anatomy and posture characteristics between groups at various stages of maturation.

Methods: Clinical measures of pelvic angle (PA), hip anteversion (HA), standing Q-angle (StQ), tibiofemoral angle (TFA) genu recurvatum (GR), anterior knee laxity (AKL), femur length (FL), tibia length (TL), tibial torsion (TT), navicular drop (ND) and general joint laxity (GJL) were measured bilaterally in 173 adolescents (88 M, 14.3±2.8 yrs, 163.4±15.6 cm, 57.5±19 kg; 85 F, 14.3±3.1 yrs, 156±21 cm, 57.8±26.7 kg) as part of a larger risk factor screening project. The average of three measurements for each characteristic and limb were calculated and the grand mean of the two limbs were used for analysis. Subjects were classified into 3 maturation groups (MG) based on validated sex appropriate, self-administered questionnaires that assessed Tanner's stages (1–5) of development. Subjects were assigned to MG1 if they were in Tanner's stages 1 and 2 (N=26 M, 25 F), MG2 if they were in stages 3 and 4 (N=34 M, 29 F), and MG3 if they were in stage 5 (N=28 M, 31 F). Separate 2 × 3 factorial ANOVAs examined sex differences in each alignment characteristic across MGs.

Results: Significant changes (all P≤.001) across MGs (1 vs. 2 vs. 3) occurred with PA (9.3°±4.4° vs. 8.2°±3.5° vs. 10.8°±3.8°), HA (10.5°±5.8° vs. 14.1°±5.9° vs. 10.9°±5.0°), TFA (10.1°±2.3° vs. 9.5°±2.1° vs. 8.6°±2.3°), GR (6.4°±2.0° vs. 7.2°±1.9° vs. 2.7°±3.6°), AKL (10.0±2.3 mm vs. 8.4±2.2 mm vs. 7.7±2.1 mm), FL (36.0±2.6 cm vs. 40.6±2.8 cm vs. 45.7±5.1 cm), TL (32.4±2.6 cm vs. 36.7±2.6 cm vs. 37.7±2.4 cm), TT (15.7°±8.2° vs. 19.9°±6.9° vs. 23.1°±7.1°), and ND (9.5±4.4 mm vs. 7.8±3.1 mm vs. 6.5±3.9 mm). Females were consistently higher than males (F vs. M) for HA (12.8°±6.0° vs. 11.1°±5.5°, P=.028), TFA (10.1°±2.1° vs. 8.7°±2.3°, P<.001), and GJL (1.5±1.7 vs. 0.9±1.3, P=.006) while males were consistently higher than females for FL (40.3±2.6cm vs. 41.7±5.7cm, P=.003) and TL (35.1±2.7 cm vs. 36.0±3.7 cm, P=.037). No sex differences were present in PA (9.5°±3.6° vs. 9.3°±4.0°, P=.939), GR (5.1°±3.3° vs. 5.7°±3.2°, P=.277), TT (18.6°±7.5° vs. 20.8°±8.2°, P=.056), or ND (7.7±3.5 mm vs. 8.0±4.4 mm, P=.561). Sex differences in StQ and AKL changed by MG. StQ values were similar for F vs. M for MG1 (15.1°±4.4° vs. 14.2°±5.0°), with higher values for F vs. M for MG2 (17.7°±5.8° vs. 11.1°±3.9°) and MG3 (16.5°±5.5° vs. 10.2°±5.2°). AKL values decreased in similarly in both groups with lower values for F vs. M for MG1 (9.2±2.0 mm vs. 10.8±2.4 mm) and MG2 (7.6±1.6 mm vs. 9.0±2.4 mm). AKL values were similar in MG3 (7.9±2.0 mm vs. 7.5±2.2 mm) as males continued to decrease while females leveled off.

Discussion: We observed a general change in posture between MGs that began with greater knee valgus, knee recurvatum and foot pronation in MG1, then moving toward a relative straightening and external rotation of the knee, and supination of the foot in later MGs. While the majority of the measures changed similarly in males and females across MGs, decreases in StQ and AKL were greater in males while females were observed to have a more inwardly rotated hip and valgus knee posture compared to males, particularly in later MGs.

Conclusions: Lower extremity anatomical and posture characteristics differ between maturational groups and appear to be sex specific. Research is ongoing to examine how these sex and maturational differences interact to influence dynamic function and injury risk.

A portion of these data were previously presented at the 54th Annual Meeting of the American College of Sports Medicine, May 30–June 2, 2007, New Orleans, LA.

Abstract #22

Subject Specific Computational Modeling to Predict the Effect of Anatomy on ACL Loading

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Introduction: High ACL loading usually occurs during the landing and/or stance phase of movements, incorporating rapid changes in speed and/or direction. Research on injury prevention is focused mainly on movement mechanics and neuromuscular training programs (e.g. [2;4]). There are also strong indications, however, that the knee itself is an important element of injury risk[5]. In this groundwork we only demonstrate our capability to generate computational joint mechanics model of the knee using the prescribed methodology. This study will be used further to analyze the effect of knee morphology on ACL landing.

Methods: Two tibio-femoral joint models were developed, one male and one female. Sagittal plane MRI scans of 26 year old male and 21 year old female were used to digitize the articulating surfaces and ligament insertion areas. Each of the four ligaments (ACL, PCL, MCL and LCL) was represented by 3 line elements in the model. Ligament and articular cartilage stiffness parameters were taken from earlier work[1]. Simulations were performed with software for 3D-quasi static joint modeling[3]. We applied combined anterior drawer force of 300 N and internal rotation moment of 5 Nm on the tibia, on each model, while changing the flexion angle from 0° to 75° in steps of 15°. We repeated the simulations by applying weight bearing condition of 100 N and 300 N on each model. Total ACL load was extracted from the simulations and compared between the two models. No statistical analysis is conducted at this point as the models are not validated and only one model per gender is developed.

Results: The female knee joint model predicted increase in ACL loading as flexion angle increased whereas, the ACL loading slightly decreased in the male knee joint model (Figure 1). ACL load increased with higher weight bearing load, in both male and female joint model.

Discussion: These preliminary results demonstrate the potentially large effects of knee joint morphology on ACL loading. The stiffness parameters and modeling structures were kept the same while adopting the same methodology for building each model. Furthermore, we applied the same loading conditions to each model. The only difference in the models was the knee morphology digitized from MRI scans. Thus, the difference observed in male and female ACL loading is purely the effect of differences in knee morphology. The female knee had much larger ACL loading at high flexion angles during anterior drawer and internal rotation. The reverse was the case in some other loading conditions. Because only one model was generated for each gender, generalization across gender is presently not warranted. Further work is needed to incorporate subject-specific tissue properties via laxity testing, and to

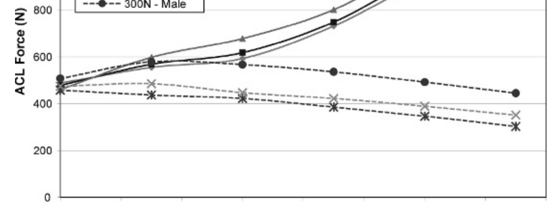

Figure 1. ACL Loading due to combined Anterior Drawer force and Internal Rotation Moment, for male and female models with different weight bearing conditions.

validate the models. Our long term goal is to use this modeling procedure to identify which loading conditions may be hazardous to a specific athlete's knee joint.

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Abstract #23

The Tibial Plateau and Its Influence on the Biomechanics of the Tibiofemoral Joint: A Sex-Based Comparison in a Blinded Study

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Introduction: The geometry of the tibial plateau is complex and asymmetric. Prior research has characterized subject-to-subject differences in tibial plateau geometry in the sagittal plane with a single parameter, the posterior slope; while the actual medial tibia slope (MTS) and the lateral tibia slope (LTS) of the plateau may be different. The lateral-to-medial directed coronal tibial slope (CTS) of the plateau has not been studied. The geometry of the tibial plateau is important because it is thought to have a direct effect on anterior cruciate (ACL) loading during at risk activities that produce high loads across the knee. We hypothesize that when considering the tibial plateau, 1) the MTS is different than the LTS in each subject; 2) there exist sex based differences in the slopes of the tibial plateau in the sagittal and coronal planes.

Methods: The MTS, LTS, and CTS of the tibial plateau were measured using sagittal and coronal MRI images obtained from the knees of 33 female and 22 male subjects. Student t-tests were performed to assess the significance of any differences in MTS, LTS, and CTS between sexes. Paired t-tests were performed to assess the significance of any differences between MTS and LTS within each subject. MTS and LTS were compared between sexes using a t-test. Two-dimensional MTS-LTS, MTS-CTS, and LTS-CTS planes were constructed to serve as a potentially viable screening tool for anterior cruciate ligament injury.

Results: The MTS and LTS were different in each subject. Additionally, the MTS and LTS of the female subjects were significantly greater than those of the male subjects ($p < 0.05$). In contrast, the CTS of female subjects were significantly less than those of the male subjects ($p < 0.05$). The correlation between MTS and LTS was poor in both populations however the review of the MTS-LTS relationship revealed that a majority of the women have high MTS-LTS values while the opposite is true for men.

Discussion: The proposed MTS-LTS plane, Figure 1, reveals that a majority of female subjects are located in the top right quadrant of the plane indicating a combination of high MTS and LTS while the opposite is true for male subjects. The higher tibial slope values in females suggest that, at low flexion angles, the anterior shear component of the joint contact force will be larger and could therefore contribute to higher levels of anterior tibial translation during load-bearing activities. The differences between the medial and lateral slopes are also important contributing to the susceptibility of subjects to either internal or external rotation of the knee during the ensuing injury causing instabilities.

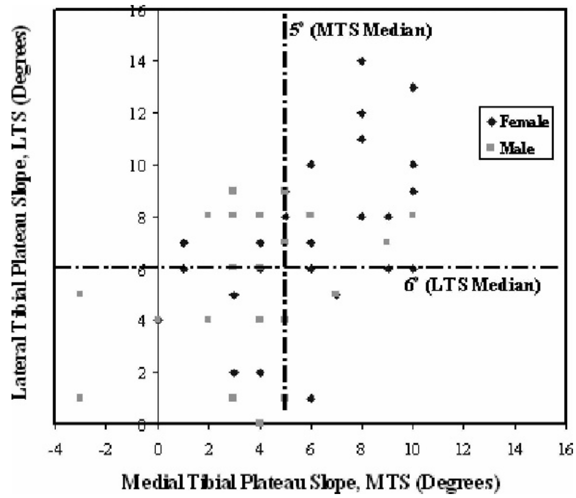

Figure 1. The MTS-LTS tibial slope plane. The female subjects are concentrated on the top right quadrant indicating highest MTS and LTS.

Conclusions: The value of this anatomic difference between the sexes needs further evaluation. For example, the increased MTS and LTS values in women compared to men should be further studied to evaluate any association with ACL injury risk. Additionally, the proposed tibia slope plane could be used to study the at-risk tibial geometry for the injured population. Finally, the male-to-female differences in the tibia plateau geometry could be essential considerations in knee injury risk assessment and reconstruction procedures.

Abstract #24

Accessory Knee Joint Motion Differs by Sex During Transition From Non-Weight Bearing to Weight Bearing

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Introduction: Previously, we demonstrated that greater anterior knee laxity (AKL) resulted in greater anterior tibial translation (ATT) during the transition from non-weight bearing to weight bearing, but did not have sufficient power to determine if this relationship was different between sex. Additionally little is known how frontal and transverse plane motions associated with ATT may differ by sex. Thus, the purpose of our study was to assess ATT and frontal and transverse plane knee motion during weight acceptance in male and females with similar knee laxity values. A secondary purpose was to assess muscle reactions in response to weight acceptance.

Methods: The dominant knee of 39 females (22.0±2.8 yrs; 163.1±6.7 cm; 58.3±6.0 kg) and 28 males (22.6±2.8 yrs; 179.7±10.0 cm; 83.8±12.4 kg) was first measured for AKL using a knee arthrometer (prescreening was done to ensure a broad distribution in both males and females) and genu recurvatum (GR) using a standard goniometer. ATT and accompanying accessory motions were measured with the subject supine in the Vermont Knee Laxity Device (VKLD). The VKLD allows controlled loading of the tibiofemoral joint by first creating a zero shear load condition across the knee while it is un-weighted to establish an initial neutral position of the tibia relative to the femur, then applies a compressive load of 40% body weight through the ankle and hip axes to simulate weight-bearing. Electromagnetic position sensors attached to the segments measured 3D motion of the joint (valgus and external rotation defined as positive) while surface EMG of the medial and lateral hamstrings (MH, LH) and quadriceps (MQ, LQ) were collected during the transition from non weightbearing to weightbearing. For females testing was performed during the first 6 days of menses. Independent T tests examined sex differences for laxity and motion while a 2×2×2 ANOVA (sex × muscle group × muscle side) examined differences in reflex response times (ms) and amplitudes (percent of maximal voluntary isometric contraction (%MVIC)).

Results: As expected, there were no sex differences in AKL (F=6.8±2.3 mm; M=6.6±1.8 mm; P=.742) or GR (F=3.8±3.8°; M=3.4±4.2°; P=.743). While there was no sex difference in the amount of ATT during the transition from non-weight bearing to weight bearing (F=7.6±2.0 mm; M=7.8±3.5 mm; P=.811) females experienced significantly greater varus (F=−2.1±2.3°; M=−1.0±1.9°; P=.042) (Range: F=−6.5–5.7°; M= −4.0–2.3°) and external rotation (F=0.8±2.3°; M=−0.8±2.1°; P=.004) (Range: F= −4.2–6.4°; M= −4.2–4.7°) motion compared to males. Additionally a significant 3-way interaction (P=.025) in muscle reflex amplitude revealed females had greater activation amplitude of their MQ (F=10.1±4.0%MVIC; M=7.7±4.1%MVIC) and LH (F=4.3±2.4%MVIC; M=2.8±2.1%MVIC). There were no sex differences in muscle onset times.

Discussion: Although the average differences were small, we observed that females experienced a greater range of variability in the amount of varus and more notably external rotation motion at the knee during weight acceptance. Further, these differences were accompanied by greater reflex amplitudes of the MQ and LH in females. The source of this difference and greater variability is unclear, but may be due to sex differences in anatomy (e.g. tibial slope geometry), alignment (e.g. hip anterversion, quadriceps angle) or neuromuscular factors.

Conclusions: During low axial loads females demonstrated greater varus and external rotation motion at the knee joint when transitioning from non-weight bearing to weight bearing. Future work should determine the underlying cause of these accessory motion sex differences and how they may affect ACL loading.

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RISK FACTOR SCREENING AND PREVENTION

Abstract #25

History of Prior ACL Injury as a Risk Factor for Incident ACL Injury

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Introduction: A positive history of previous ACL injury is widely considered to be a strong predictor of incident ACL injury. One possible reason for this association is that high-risk movement patterns may predispose individuals to both initial and repeat injury. We explored the epidemiologic and biomechanical relationship between previous ACL injury and incident ACL injury. The aims are to: 1) quantify the significance of previous ACL injury as risk factor for incident ACL injury, and 2) compare jump-landing biomechanics between subjects with prior ACL injury and subjects with no prior ACL injury.

Methods: Data from the first two years of a 4-year prospective cohort study (JUMP-ACL) were used. The JUMP-ACL study is being conducted in the three large service academies (U.S. Air Force Academy, U.S. Military Academy, and U.S. Naval Academy). During the summer before their freshman year, incoming male and female cadet-officers completed a questionnaire and performed three trials of a standardized jump-landing task. The jump-landing task was a forward drop-jump from a 30 centimeter box onto a forceplate (Bertec Corporation Model 4060-NC) followed by rebound to maximal height. A Flock of Birds/Motion Monitor system (Innovative Sports Training, Chicago IL) captured kinematic data. The three trials were averaged. Subjects are being prospectively followed to identify all incident ACL injuries.

Results: Complete test data are currently available for 2,685 subjects, with females comprising 39% (1039/2691). As of Oct-01-2007, 34 subjects had suffered surgically-confirmed incident ACL injury or strongly suspected probable injuries awaiting surgical confirmation (incidence rate of 5.2 per 1,000 person-years).

AIM 1: 85/2,691 subjects (3.2%) reported a previous history of ACL injury prior to baseline testing; 9 of these subsequently had an incident ACL injury during study follow-up (10.6%). In contrast, 25/2,600 with no prior history of ACL injury developed had an ACL injury during study follow-up (1.0%). In Poisson regression models (adjusted for gender and body weight) those with a previous history of ACL injury had an ten-fold greater rate of incident ACL injury (rate ratio=10.4; 95%CI: 4.9, 22.7; $p<0.01$).

AIM 2: We compared baseline biomechanical measures for subjects with prior ACL injury to subjects with no prior ACL injury. In a series of multivariate stepwise logistic regression models, the kinematic factors most strongly associated ($p<0.05$) with prior ACL injury were tibial adduction angle and hip adduction angle at initial ground contact, peak knee varus and knee flexion angles over the landing phase, hip flexion angle at the instant of peak posterior ground reaction force, and peak hip extension, knee flexion, and knee extension angles over the entire stance phase. From the same models, the kinetic factors most strongly associated ($p<0.05$) with prior ACL injury were peak hip flexion and knee extension moments over the landing phase, and peak hip flexion, hip internal rotation, and hip adduction moments over the entire stance phase.

Conclusions: Prior history of ACL injury is an important risk factor for incident ACL injury, and subjects with prior ACL injury have different jump-landing biomechanics than subjects with no prior ACL injury. It is currently unclear whether the distinct biomechanical factors of the prior ACL injury cohort are important predictors of ACL injury or simply the sequalae of previous ACL injury.

Abstract #26

Lower Extremity Strength as Risk Factors for ACL Injury: Preliminary Data

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Introduction: Decreased strength of the hip and hamstring musculature are theorized to be risk factors for ACL injury, while increased strength of the quadriceps musculature is theorized to be a risk factor for ACL injury. Many injury prevention programs utilize lower extremity strengthening exercises in hopes of decreasing the risk of ACL injury. The purpose of this investigation was to determine if lower extremity isometric strength is a risk factor for ACL injury in a large sample of physically active individuals.

Methods: 2563 (Non-injured: n=2542, height=173.55±9.18 cm, mass=71.89±12.83 kg; Injured: n=21, height=174.21±8.95 cm, mass=76.77±14.98) freshmen at the United States Air Force Academy, United States Military Academy, and United States Naval Academy volunteered to participate in this investigation. Participants were followed for approximately two years for diagnosis of an ACL injury. Twenty-one participants (10 female, 11 males) suffered an ACL injury during the follow up period. Baseline testing for all participants consisted of assessing isometric strength for the knee flexors (KFLEX) and extensors (KEXT), and the hip external rotators (HER), internal rotators (HIR), abductors (HABD), and extensors (HEXT) using a hand-held dynamometer. Each participant performed two trials of each strength test and the mean and peak force (N) for each trial was recorded. Thigh and shank length were also assessed so that the force measures could be converted to torque (Nm). Independent sample t-tests were performed to determine differences in torque measures across the injured and non-injured groups. Additionally, Poisson regressions were performed to determine if a combination of gender, mass, and torque predicted ACL injury. Alpha level was set a priori at 0.05.

Results: The injured group had significantly higher raw torque values for mean (Non-injured=135.08±43.65 Nm, Injured=154.91±55.11 Nm, P=0.04) and peak (Non-injured=156.82±51.46 Nm, Injured=180.06±70.79 Nm, P=0.04) KEXT, mean HER (Non-injured=58.13±18.27 Nm, Injured=66.60±20.72 Nm, P=0.04), and mean (Non-injured=98.37±31.99 Nm, Injured=112.97±31.87 Nm, P=0.04) and peak (Non-injured=115.07±37.53 Nm, Injured=132.46±42.48 Nm, P=0.04) HABD. No significant differences were found for the other torque values ($P>0.05$). ACL injury was significantly predicted when gender was combined with each of the following torque measures in separate regression models: KEXT mean (P=0.04) and peak torque (P=0.04), HER mean (P=0.03) and peak torque (P=0.05), and HABD mean (P=0.04) and peak torque (P=0.03). When gender and mass were combined with each torque measure, ACL injury was not significantly predicted ($P>0.05$). Also, when mass was combined with each torque measure, ACL injury was not significantly predicted ($P>0.05$).

Discussion: The participants that suffered an ACL injury were stronger on measures of KEXT, HER, and HABD compared to the non-injured subjects. Additionally, when gender was combined with each of the significant measures, the models significantly predicted ACL injury. Although the findings of increased HER and HABD as a risk factor for ACL injury are not what we expected, it is possible that the participants suffering an ACL injury were more physically active and therefore have increased hip strength compared to the non-injured subjects.

Conclusions: Due to the preliminary nature of this data, the findings from this investigation are not conclusive. We anticipate more participants in the cohort to suffer an ACL injury and therefore a possible change in the strength measures reported as risk factors for ACL injury.

Abstract #27

The Effects of Leg Dominance and Strength Imbalance in the Kinematics of Female Recreational Athletes in a Stop-Jump Task

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Introduction: Lower extremity strength imbalance has been shown to be a possible risk factor for anterior cruciate ligament injury and lower extremity athletic injury in general. Previous studies have also demonstrated differences in the kinematics of the dominant (DOM) and non-dominant (NDOM) lower extremities during an athletic task. Either of these factors may place both limbs at an increased risk of injury due to limb compromise or over-reliance, and may be possible targets for intervention. The purpose of this study is to examine the effects of limb dominance and strength imbalances in the kinematics of female recreational athletes during a task often associated with ACL injury.

Methods: A total of 66 female recreational athletes enrolled in an ongoing investigation were assessed for inclusion into this study. Three cohorts were created, consisting of 1) subjects with at least 15% less strength in their gluteus medius (GMED) of their non-dominant limb compared to their dominant limb; 2) subjects with at least 15% less strength in their quadriceps (QUAD) of their non-dominant limb compared to their dominant limb; and 3) subjects with less than a 10% strength imbalance between their dominant and non-dominant limbs in both their gluteus medius and quadriceps muscles (NONE). Limb dominance was defined as the subjects' preferred limb for kicking a soccer ball for maximum distance. Strength was assessed by a maximum voluntary contraction using a hand-held dynamometer. The first 10 qualifying subjects for each group were selected for this study for 30 total subjects. GMED (age 22.5±3.4 yrs, ht 1.67=±.08 m, wt 62.2=±8.3 kg, ave. diff. 20%), QUAD (age 22.6±4.1 yrs, ht 1.68±.08 m, wt 63.3±11.5 kg, ave. diff. 23%), and NONE (age 21.4±3.7 yrs, ht 1.65±.07 m, wt 58.4±10.2 kg, ave. GMED diff. 3%, ave. QUAD diff. 3%). Lower extremity kinematics were collected during 5 stop-jump trials using three-dimensional videography. Dependent variables included knee valgus and flexion angles, and hip abduction and flexion angles. All dependent variables were taken at the point of peak vertical ground reaction force during the landing phase. Statistical analyses were performed using a 3 [group] × 2 [limb] ANOVA ($\alpha<.05$). Dependent samples t-tests were performed to investigate significant interactions.

Results: No significant main or interaction effects were observed in any of the dependant variables ($\alpha>.05$).

Discussion: The results indicate that lower extremity limb dominance and moderate lower extremity strength imbalances may not significantly alter athletic task performance in female recreational athletes. However, these results may not account for other factors, such as different fatigue thresholds, that may occur during athletic performance.

Conclusions: Mild to moderate lower extremity strength imbalances may not be a significant risk factor for injury. Further study into larger strength imbalances, fatigue, and multi-muscle strength imbalances using prospective study designs, alternative athletic tasks, and larger sample sizes may be warranted.

Note: This abstract was originally presented at the Southeastern Biomechanics Conference in 2007

Abstract #28

A Lack of Correlation between Static and Dynamic Measures of Postural Stability

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Introduction: Static balance has been used to assess postural stability (PS) and potential predisposition to injury; yet, female athletes, who are at greater risk for noncontact anterior cruciate ligament injury (ACL), demonstrate better single-leg static balance than male athletes. A dynamic functional assessment of balance seems indicated although the relationship between dynamic and static measures of PS has yet to be quantified. The purpose of this study is to determine if a relationship exists between static and dynamic single-leg measures of PS in physically active females. It is hypothesized that no relationship exists.

Methods: A total of eight physically active females (age: 21.5±0.8 yrs, mass: 62.3±7.9 kg, height: 165.6±5.4 cm) volunteered. Subjects reported no history of lower extremity surgery and no lower extremity injury within six months prior to testing. Postural stability was assessed using two static single-leg balance tasks (eyes open and eyes closed), and two dynamic balance tasks (anterior-posterior (AP) and medial-lateral (ML) jump). Static balance included right leg stance with hands on hips. Dynamic balance included a double-leg jump, single-right leg land, and attempt to stabilize quickly on one leg. Once stabilized subjects placed their hands on their hips and maintained single-leg balance for an additional 10 s. Jumps were performed over a 12″ (AP jump) or 6″ (ML jump) hurdle placed halfway between the force plate and a jump distance normalized to % subject height, 40% for AP and 33% for ML. Vertical, AP and ML ground reaction forces (GRFs) were collected using a force plate. For static balance, standard deviation (stdev) for each GRF was averaged across three 10 s trials. For five dynamic balance trials, mean postural stability indices were calculated using GRFs identified within the first three seconds post initial contact. Index calculations are as follows: AP stability index (APSI) = $[\sqrt{(\Sigma(0-GRFx_i)^2)}]$/body weight, ML stability index (MLSI) = $[\sqrt{(\Sigma\ (0-GRFy_i)^2)}]$/body weight, vertical stability index (VSI) = $[\sqrt{(\Sigma\ (\text{body weight}-GRFz_i)^2)}]$/body weight. A series of 12 bivariate correlations were computed between the vertical, AP, and ML measures across dynamic and static balance assessments. An alpha level of 0.05 was set a priori to determine significant correlations.

Results: None of the 12 computed Pearson correlation coefficients achieved statistical significance (p-value range=.06 to 0.937, correlation coefficient range= −0.44 to 0.69).

Discussion: Postural stability testing provides important insight into the underlying sensorimotor control mechanisms necessary for dynamic joint stability. The results of this study indicate that no relationship exists between the static and dynamic measures of PS tested suggesting that a dynamic assessment of PS may be a more functional assessment for risk of ACL injury.

Conclusion: Future studies examining risk factors and modification of risk factors for noncontact ACL injury should incorporate a dynamic measure of postural stability.

Abstract #29

The Influence of an ACL Injury Prevention Program on Knee Valgus Moments During Cutting: An Evaluation of Pre-Pubertal, Pubertal and Post-Pubertal Female Athletes

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Introduction: Several injury prevention programs have been found to reduce the incidence of anterior cruciate ligament (ACL) injuries in female athletes, however little is known about the mechanism underlying their success. Given that a high knee valgus moment has been reported to be a predictor of anterior cruciate ligament injury risk in female athletes,[1] it stands to reason that participation in an ACL injury prevention program should result in a decrease in the frontal plane loading at the knee. The purpose of this study was to quantify the influence of an exercise program that has been shown to reduce ACL injury risk on knee valgus moments during side-step cutting. A secondary purpose was to evaluate whether female athletes at different stages of maturation respond differently to this form of training.

Methods: Forty eight soccer players (ages 9-17) with no history of knee injury took part in this study. Subjects were assigned a maturation phase based on stages of pubertal development; pre-pubertal (n=11), pubertal (n=19), and post-pubertal (n=18). The Pubertal Maturation Observational Scale[2] and a self-report of Tanner stages for pubic hair development were used to group participants. Subjects participated in the Prevent injury and Enhance Performance (PEP) training program as part of their normal soccer practice. The program was administered two times a week during a 10 week soccer season. The PEP program was selected because is has been shown to significantly reduce ACL injuries.[3] Biomechanical testing was performed prior to and immediately following the soccer season. Subjects were instructed to perform a side-step cutting maneuver at 4–5.0 m/s by planting their right foot and changing direction to the left at a 45 degree angle. The subjects were randomly cued to perform this task by a light signal that was activated shortly after initiation of the task. Anthropometric data, 3-D kinematics (8 camera, VICON Motion System, 250 Hz), and ground reaction forces (AMTI force plate, 1500 Hz) were used to calculate peak knee external valgus moments (inverse dynamics) during the deceleration phase of cutting. Moment data were normalized to body mass and height. To determine if knee valgus moments differed between groups over time (pre season vs. post season) a 2 × 3 ANOVA with repeated measures for time was performed.

Results: ANOVA results revealed a significant main effect of time ($p=0.02$). When averaged across maturation groups, peak valgus moments were significantly lower post-training (0.49 Nm/kg·cm vs. 0.56 Nm/kg·cm). There was no significant main effect of group or group × time interaction (p-values of 0.51 and 0.72 respectively).

Discussion: On average, subjects demonstrated a 14% reduction in the peak knee valgus moment during cutting after participating in a 10 week training program. This decrease was consistent across all three groups, indicating that female athletes respond similarly to this program regardless of the stage of physical maturation. We postulate that the observed reduction in the knee valgus moment may in part, be responsible for the decreased injury risk that has been associated with this particular injury prevention program.

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Abstract #30

A 12-Week Pre-Practice Exercise Intervention Decreases Ground Reaction Forces During Jumping in High School Basketball Players

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Introduction: Increased ground reaction forces and poor lower extremity movement patterns are thought to contribute to lower extremity injuries such as anterior cruciate ruptures. Exercise interventions have subsequently been developed in attempt to change these movement patterns and prevent lower extremity injury. Program participants all perform the same exercises without regard to individual movement patterns. It is thought that a customized exercise intervention prescribed based on alterations in lower extremity movement patterns may be more effective in improving lower extremity movement patterns as exhibited by decreased ground reaction forces. Therefore, the purpose of this study was to compare the effects of a customized (CUS) and generalized (GEN) exercise program on lower extremity mechanics during a jump-landing task. We hypothesized that the CUS program compared to the GEN program would be more effective in minimizing ground reaction forces.

Methods: Forty eight high school basketball players were assigned to the CUS program (n=29; age=16±1 yrs; height=175±11 cm; mass=70±12 kg) or to the GEN program (n =19; age=15±1 yrs; height=176±14 cm; mass=67±9 kg) performed before practice for 12 weeks. The varsity boys and girls teams as well as the junior varsity and freshman girls teams were assigned to the customized (CUS) exercise program. The junior varsity and freshman boys teams were assigned to the generalized (GEN) exercise program. The GEN program emphasized increasing sagittal plane lower extremity strength and flexion during jumping as well as lower extremity flexibility. The CUS program was based on athlete's performance of a standardized double leg squat and emphasized hip abductor/adductor and dorsiflexor/plantarflexor muscle balance. All individuals in the CUS group also performed exercises which promoted control of sagittal, frontal and transverse plane motions. An electromagnetic tracking system and force plate was used to assess lower extremity biomechanics during a jump-landing task before and after the 12 weeks. Participants performed 3 jump-landings from a 30-cm high box placed 50% of subject's height from the front of the force plate then upward for maximal vertical height. Peak vertical ground reaction force (PVGRF) as well as anterior-posterior (AP) ground reaction force (APGRF) at PVGRF and medial-lateral (ML) ground reaction force (MLGRF) at PVGRF were collected. The average value from the 3-trials were normalized to body mass then analyzed using separate mixed model ANOVAs and Tukey's HSD test. ($\alpha \leq 0.05$).

Results: There was a significant time by group interaction effect which indicated the CUS group demonstrated significantly (p=.03) less PVGRF (14.1±.4 N/kg) after 12 weeks than the GEN group after (18±6 N/kg) the exercise program. There were significant main effects for time indicating that APGRF (Pre = 11±3 N/kg, Post = 10±2 N/kg; p=.02) and MLGRF (Pre = 4±2 N/kg, Post = 3±2 N/kg; p<.01) were significantly less after both exercise programs.

Discussion: Our data show that the CUS program was more effective in decreasing VPGRF and that both exercise programs decrease APGRF and MLGRF in high school basketball players. This decrease in the overall load is likely to decrease the lower extremity external moments and may minimize the risk of lower extremity injuries.

Conclusions: Pre-practice exercise programs appear effective in decreasing ground reaction forces during a jump landing task. Further investigation is needed to examine effects of exercise programs on lower extremity kinetics and kinematics during high risk movement patterns such as jumping.

Abstract #31

Movement Change Retention Following an Anterior Cruciate Ligament Injury Prevention Program

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Introduction: Anterior cruciate ligament (ACL) injury prevention programs have shown promising results in reducing injuries and changing theoretical neuromuscular risk factors, such as movement patterns during jump landings. While these movements may change after the completion of a program, it is unknown how long individuals retain these changes. Therefore, the purpose of this study was to evaluate retention scores in landing errors following an ACL injury prevention program.

Methods: An ACL injury prevention program was implemented to 72 youth soccer players (males: n=22, age=11±1 years, height=152.7±11 cm, mass=39.4±8 kg; females: n=50, age=12±2 years, height=158.5±8 cm, mass=48±9 kg). Subjects performed the ten-minute program during team warm-ups before every practice for 9 months consisting of various static stretching, strengthening, agility, and plyometric exercises. Subjects performed three jump landing trials before (pre-test) and after (post-test) completing the injury prevention program, as well as 3 months following the program (retention). The jump landing task required subjects to jump forward a distance of half of their body height from a box 30cm high. Subjects jumped up for maximal vertical height immediately upon landing. The frontal and sagittal plane views of all trials were videotaped and later scored using the Landing Error Scoring System (LESS). The LESS is a valid and reliable clinical motion analysis tool that is scored using a binary system based on jump landing characteristics including: knee flexion, knee valgus, hip flexion, and trunk flexion angles, as well as foot rotation and stance width. A higher LESS score indicates a greater number of landing errors present during the jump landing task. The average total LESS score was calculated for all three testing sessions. A change score was calculated between the retention score and the pre-test score, meaning a negative change score showed an improvement in LESS score or landing technique. A univariate ANOVA, adjusting for age, was performed to compare the change score between gender and an independent variable defined as IMPROVEMENT. IMPROVEMENT was calculated so subjects (n=11 males, 32 females) who improved their average LESS score between the first two testing sessions, pre-test and post-test, and subjects (n=11 males, 18 females) who did not improve could be compared.

Results: Significant main effects for gender ($F_{1,67}$=5.95, *P*=0.017) and IMPROVEMENT ($F_{1,67}$=10.82, *P*=0.002) were observed for the change score between the pre-test and retention test. Girls (Mean±SE:−1.48±0.28) had a greater change score than boys (−0.22±0.42). Subjects who improved their LESS score after completion of the injury prevention program (−1.65±0.33) had a greater change score than subjects who did not improve (−0.06±0.36).

Discussion: The majority of girls improved their landing technique after completing the injury prevention program and these improvements remained 3 months later. Boy soccer players started off with better landing technique compared to girls and any improvement that occurred following the program decreased during the time frame between finishing the program and 3 months later. Overall, improvements observed after the program completion were still present at the retention session while subjects who either did not change or worsened their landing technique appear to return to their initial level of landing errors.

Conclusions: Improvements in landing technique following an ACL injury prevention program remain even after 3 months of not performing the exercises in youth soccer players. Girls retain these improvements more than boys, which may be because they had greater room for improvement. The results of this study are very promising for the long-term effects of injury prevention programs and their potential impact on injury rates.