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Biomechanical Sex Differences Between Freshman and Sophomore Athletes in a Single-Leg Squat and Single-Leg Land

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BIOMECHANICAL SEX DIFFERENCES BETWEEN FRESHMAN AND SOPHOMORE ATHLETES IN A SINGLE-LEG SQUAT AND SINGLE-LEG LAND

by

CAREN WALLS

(Under the Direction of Bryan Riemann)

ABSTRACT

The purpose of this study was to investigate sex differences in single-leg squat kinematics and single-leg landing kinetics between freshman and sophomore athletes. Single-leg squat results revealed women had greater peak knee lateral rotation displacement, but no difference in total angular distances. Freshman and sophomore women were similar for peak angles and angular distances. Multivariate analysis of peak net joint moments normalized to body mass identified differences between men and women with separating variables being hip extension, hip medial rotation and knee lateral rotation moments. All three variables were greater in men. Subgroups were separated by hip medial rotation, with freshman men being greater than freshman and sophomore women. There were no sex differences for moments normalized to momentum at ground contact. The separating variable between subgroups was ankle extension with freshman women being greater than both freshman men and sophomore women.

INDEX WORDS: Anterior cruciate ligament, Sex differences, Kinematics, Kinetics

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by

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CHAPTER 1: INTRODUCTION

In light of Title IX, increasing amounts of women are participating in sports and certain injury rate differences between men and women have come to attention.[1] Overall, 70% of all anterior cruciate ligament (ACL) tears occur during athletic participation[2] with injury rates in women two to four times higher in comparison to men.[3, 4] Many intrinsic and extrinsic factors are suggested to explain the disparity of ACL injuries between men and women; although it is most likely that one single factor does not explain the disproportionate number of ACL injuries experienced by women. Internal factors are postulated to include: joint laxity,[5, 6] ligament size,[7] lower extremity malalignment,[5, 8, 9] hormone influences,[10-12] and intercondylar notch configuration.[7] Extrinsic factors are postulated to include: muscular strength imbalances,[7, 13, 14] playing surfaces,[15] skill and conditioning levels, and biomechanical execution of tasks.[2, 14, 16-24]

Sex differences in the biomechanical execution of motor tasks has received much attention as it is recognized that specific kinematic and kinetic alterations could influence stress on the ACL.[2, 14, 16-21, 23] Research suggests that women tend to use mechanics that place them at more of a risk for ACL injury. These mechanics include women using less knee flexion during landing and cutting,[14, 17, 18, 25] greater knee valgus angles,[2, 19] decreased hamstring activation and increased quadriceps activation,[26] decreased hip flexion,[18, 27] more hip internal rotation,[17] and greater ground reaction forces[14] during landing. Based largely on the above documented biomechanical differences, prevention programs have been developed to train woman athletes to jump, land and cut in a more "ACL safe" manner.[26-29] The efficacy of some programs has been supported with decreased injury rates following training[26, 28] and/or the exhibition of more masculine biomechanical movement patterns, or a “safer” biomechanical movement pattern that place the ACL, theoretically, at less risk.[27, 29] The tasks most frequently examined between pre-post training include isokinetic strength,[27, 28] single-leg hop,[28] and double leg jump tests.[27, 28]

While these prevention programs have demonstrated beneficial outcomes, there are many unanswered questions regarding customizing the program to individual or small groups of women athletes, especially at the collegiate level. In our clinical experience, we have observed during pre-participation examinations of freshman women, the trend of a large percentage of woman athletes having not participated in formal sport specific, yearlong, strength and conditioning programs. Before recommending that prevention programs be implemented, either in addition to, or as partial replacement of the current strength and conditioning programs, understanding the biomechanical changes accompanying a full season of normal collegiate sports participation is warranted. Thus, the purpose of this study was to investigate biomechanics of single-leg squat, and double-leg jump with single-leg land between men and women freshman and sophomore athletes. Specifically, for the single-leg squat, trunk, hip, and knee joint range of motion were compared.[23] For the single-leg jump with single-leg land, multivariate analysis of peak net joint moments (NJM) at the hip, knee, and ankle were compared.[17] These variables were chosen for comparability to previous studies of these tasks. We hypothesized significant differences in the biomechanical execution of the tasks between men and women. We also hypothesized that sophomore women would differ from freshman women, but be more similar to freshman men because they had completed a year of collegiate athletic participation. Specifically, for the single-leg squats, we hypothesized that the women would perform with significantly less hip and knee flexion, more hip adduction and medial rotation, and more knee abduction and lateral rotation.[23] Further, while sophomore women would still be different from the freshman men, they would perform more like the men than the freshman women. We hypothesized women would perform the landing task significantly different from the men for the given set of variables of hip extension, medial rotation, and hip adduction, knee extension, lateral rotation and abduction, and ankle extension peak NJM. In addiction, we hypothesized the women would have greater peak NJM for each of these variables, with again sophomore women using mechanics more similar to freshman men rather than freshman women.

CHAPTER 2: METHODS

Subjects

Forty-two Division I freshman and sophomore athletes from the men's and women's basketball and soccer teams were deliberately chosen for this study. This included 21 men and women. Subjects were excluded if they had a major lower extremity injury within the past 12 months or history of lower extremity surgery. Major lower extremity injury was defined as second-degree strain or sprain, fracture, or an injury, which directly caused the athlete to be withheld from practice or competition for more than one month. Subjects were also excluded if they had history of neurological, vestibular or balance disorders. Investigators met with the coaches of the designated teams in the spring before testing to explain the procedures and obtain permission for their athletes to participate. Athletes were asked in August if they would voluntarily participate in the study. All subjects were assigned a subject number, which was used to identify them throughout the study to ensure confidentiality. Only the principle investigator and her advisor had access to the codes linking subject names and subject codes.

Procedures

Prior to the initiation of the study, all parts of the study were explained to the subjects. They were explained their rights, allowed to ask questions, and signed an informed consent form (Appendix C). Subjects filled out a questionnaire on their past workout, injury and resistance training history (Appendix C). Subjects were tested initially in August before the initiation of their sports' conditioning and training program. Subjects performed three maximum jumps prior to attachment of sensors. These measurements were used as reference in adjusting their target. Subjects were tested on three sets of five consecutive single-leg squat repetitions, and five trials of double-leg jumping with single-leg landing. All activities were performed with the subjects wearing standard Nike® tennis shoes provided by the biomechanics laboratory.[14] Resistance training schedules and workout detail were documented to have a clear overview of the intensity and types of each team's workout. This information was used during the results interpretation, to analyze differences in sport teams' resistance training, and possible interactions with their biomechanics.

All biomechanics testing occurred in a controlled environment using an extended range electromagnetic tracking system (MotionStar, Ascension, Inc., Burlington, VT) and two AMTI strain gauge force platforms (Advanced Mechanical Technology, Inc., Waterown, MA) with all the hardware settings in the default mode. Forceplate data were collected at 140 Hz for the single-leg squats and 1400 Hz for the jumping task. Data from the electromagnetic tracking system were collected at 140 Hz for all tasks and utilized the Motion Monitor acquisition software package (Innovative Sports Training, Inc; Chicago IL). Sensors were attached to the seventh cervical vertebra, sacrum (specifically S1-S2 junction), both feet, shanks, and thighs of the subjects using double sided tape and elastic tape. During subject setup, the ankle and knee joint centers were estimated by computing midpoints between contralateral points at each respective joint. The hip joint center was determined using a series of nine points during a circumduction movement cycle for each hip to estimate the apex of femoral motion.[30]

Task Procedures

The order of the tasks was randomized between subjects.

Single-leg Squat - Subjects stood on their dominant leg, defined by the leg which would be used to kick a soccer ball,[17, 19, 22] with hands on hips, in an upright position. Subjects squatted down as far as possible without loosing balance and returned to the starting position.[23] Three trials of five continuous squats; at a rate of one squat per two seconds were completed. An electric metronome was used to help standardize the pace. Subjects were allowed to practice with the metronome until they felt comfortable with the pace.

Double-leg jump with single-leg landing[22]- A target height of 75% of their maximum double-leg jump with single-leg landing was set using a Vertec® (Perform Better). Subjects stood with both feet on one forceplate, jumped to reach their target height with their ipsilateral hand, and landed on the dominant foot only.[17] Subjects were able to self-select their jump/land strategy and had one minute rest between each trial. Five individual jump trials were completed.[2] Subjects were allowed to practice to ensure they understood the task and felt comfortable with the placement of the Vertec®.

Data Reduction

All data reduction procedures were conducted using MatLab (The MathWorks, Inc., Natick, MA) based code. Relative three-dimensional angles were used to calculate segmental orientations between adjacent segments in the local frontal (abduction), sagittal (flexion), and transverse (rotation) planes using Euler Angles in flexion-extension, abduction-adduction, and rotation order. Because the sensor on the seventh cervical vertebra process defined the trunk segment, the trunk angle was representative of an estimation of the overall sum vertebral movements occurring from the sacrum to the seventh cervical vertebra.[31] Subject height and weight were recorded as input into anthropometric calculations required for locating each segment's center of mass using the Dempster parameters as reported by Winter. The total body center of mass (TBCM) was calculated based on the location of the segment center of masses for the eight-link model (feet, shanks, thighs, pelvis, trunk). All kinematic data were filtered using a zero-phase lag Butterworth filter (10 Hz cutoff).

Single-leg squats

Five repetitions from the 15 squats collected were selected for analysis using a graphic user interface display of the vertical TBCM trajectory. Criteria for selection included achievement of similar squat depths (±.01m), repetition time, percent cycle of maximal squat depth, and squat depth were calculated from the vertical TBCM data. Next, the peak trunk flexion, hip flexion, adduction, and medial rotation; and knee flexion, abduction, and lateral rotation angles[23] were calculated for individual repetition selected. Additionally the angular distance for trunk, hip and knee adduction/abduction and medial/lateral rotation were computed. The anterior-posterior and medial-lateral normalized center of pressure (COP) trajectory distance during each repetition were then calculated and normalized to body height. All dependent variables were then averaged across the five selected repetitionis and used for data analysis.

Single-land land

For the single leg land, the period of interest began when the vertical ground reaction force (vGRF) exceeded 5% body mass and concluded when the vertical TBCM position reached its first minima following the peak vertical impact force. The peak vGRF, peak vGRF normalized to body mass, flight time, and TBCM velocity at ground contact were then calculated. Based on the previous sex-related kinetic[14, 16-19, 22, 23, 25] research, peak ankle, knee, and hip extensor, knee abduction, and lateral rotation and hip adduction and medial rotation NJM were considered. Extension, adduction, and medial rotation were all analyzed as being positive moments, whereas abduction and lateral rotation were referenced as being negative. This required flipping the ankle and hip extensor and flipping the lift limb to match the right for the adduction and medial rotation moments. Peak NJM were computed using standard biomechanical practices.[32] Peak NJM were normalized using two different methods, to body mass and to momentum at ground contact. All dependent variables were averaged across the five repetitions and entered into the data analyses.

Data Analysis

Single-leg squat

Men versus women

Squat characteristics (squat depth, depth as % height, repetition time, cycle % to max depth) were analyzed by separate t-tests. COP trajectory distance normalized to height was analyzed by 2-way ANOVA (sex x direction) with follow-up Tukey post hoc if necessary (Table 1). Normalized COP was not normalized to foot size because it could not be guaranteed that the entire foot was in contact with the force plate during the full duration of the task. For the single-leg squat, 2-way ANOVA (sex x joint) was used to analyze peak flexion angles at the trunk, hip, and knee. Independent t-tests were used to analyze the dependant variables of peak angles for hip adduction and medial rotation, and knee abduction and lateral rotation. Angular distance for abduction/adduction at the trunk, hip, and knee were analyzed in two 2-way ANOVAs (sex x joint) with Tukey post hoc follow-up if necessary.

Men versus subgroups

Squat characteristics (squat depth, depth as % height, repetition time, cycle % to max depth) were analyzed with one-way ANOVA (group x variable) with Tukey post hoc (Table 1). Normalized COP trajectory distance was analyzed by 2-way ANOVA (sex x direction) with follow-up Tukey post hoc. For the single-leg squat, 2-way ANOVA (group x joint) was used to analyze peak flexion angles at the trunk, hip and knee. Independent one-way ANOVAs were used to analyze the dependant variables of peak angles for hip adduction and medial rotation, and knee abduction and lateral rotation. Tukey post hoc follow-up was used if necessary. Angular distance for abduction/adduction at the trunk, hip, and knee were analyzed in two 2-way ANOVAs (sex x joint) with Tukey post hoc if necessary.

Single-leg land

Men versus women

For the single-leg land, peak NJM were analyzed with a multivariate approach (Table 2). A MANOVA analyzed differences between men and women for the given variables of peak hip extension, medial rotation, adduction; peak knee extension, lateral rotation, and abduction; and peak ankle extension moments. Differences were followed-up with Tukey post hoc tests. Peak NJM MANOVAs were run normalized to body mass and to momentum at ground contact.

Men versus subgroups

For the single-leg land, peak NJM were analyzed with a multivariate approach (Table 2). MANOVAs analyzed differences between men and women subgroups for the given variables of peak hip extension, medial rotation, and hip adduction; peak knee extension, lateral rotation, and abduction; and peak ankle extension moments. Differences were followed-up with Tukey post hoc tests. Peak NJM MANOVAs were run normalized to body mass and to momentum at ground contact.

Table 1. Squat analysis and results

Variables	Data Analysis	Results
Characteristics		
Men vs. Women	Independent t-tests: squat depth, depth as % height, repetition time, % cycle of max depth	% Cycle of Max Depth: Men > Women
FR Men vs. Subgroups (FRW, SOW)	One-way ANOVA: squat depth, depth as % height, repetition time, % cycle of max depth with Tukey follow-up	% Cycle of Max Depth: FRM > FRW & SOW
Center of Pressure Distance/height		
Men vs. Women	Sex x direction ANOVA, Tukey post hoc	Sex Main effect: Men > Women Direction Main effect: anterior/posterior > medial/lateral
FR Men vs. Subgroups	Group x direction ANOVA, Tukey post hoc	Group Main effect: FRM > SOF Direction Main effect: anterior/posterior > medial/lateral
Peak Angles		
Men vs. Women	Independent t-tests: Hip Add, Hip MR, Knee Abd, Knee LR	Knee LR: Women > Men
	Sex x joint (trunk, hip, knee flexion) ANOVA, Tukey post hoc	Joint Main effect: Knee > Hip > Trunk
FR Men vs. Subgroups	One-way ANOVA: Hip Add, Hip MR, Knee Abd, Knee LR, Tukey follow-up	Knee LR: FRW & SOW > FRM
	Group x joint (trunk, hip, knee) ANOVA: flexion, Tukey post hoc	Joint Main effect: Knee > Hip > Trunk

Angular Distance Angles		
Men vs. Women	Sex x joint ANOVA: Abduction/adduction Sex x joint ANOVA: rotation, Tukey post hoc	Abd/Add Jt. Main effect: Knee & Hip> Trunk Rotation Jt. Main effect: Hip > Knee > Trunk
FR Men vs. Subgroups	Group x joint ANOVA: abduction/adduction Group x joint ANOVA: rotation, Tukey post hoc	Abd/Add Joint Main effect: Hip > Trunk Rotation Joint Main effect: Hip > Knee > Trunk

Table 2. Single-leg land analysis and results.

SL Land Characteristics		
Men vs. Women	Independent t-tests: peak vGRF, norm peak vGRF, flight time, landing phase, TBCM velocity at ground contact	Peak vGRF: Men > Women Norm Peak vGRF: Men > Women Flight Time: Men > Women TBCM velocity @ GC: Men > Women
FR Men vs. Subgroups	One-way ANOVA: peak vGRF, norm peak vGRF, flight time, landing phase, TBCM velocity at ground contact, Tukey post hoc	Peak vGRF: SOM > FRW & SOW Norm Peak vGRF: FRM > SOW TBCM velocity @ GC: FRM > FRF & SOF

SL Land peak NJM norm Body Mass		
Men vs. Women	MANOVA: hip extension, hip medial rotation, hip adduction, knee extension, knee lateral rotation, knee abduction, ankle extension moments; descriptive discriminant analysis	Sig. sex difference, separating variables: Hip medial rotation: Men > Women Knee lateral rotation: Men > Women Hip extension: Men > Women
FR Men vs. Women Subgroups	MANOVA: hip extension, hip medial rotation, hip adduction, knee extension, knee lateral rotation, knee abduction, ankle extension moments; descriptive discriminant	Sig. group difference, separating variables: Hip medial rotation: FRM > FRW & SOW Ankle extension: FRW > FRM > SOW
SL Land peak NJM norm Moment. at GC		
Men vs. Women	MANOVA: hip extension, hip medial rotation, hip adduction, knee extension, knee lateral rotation, knee abduction, ankle extension moments; descriptive discriminant analysis	No significant sex difference
FR Men vs. Women Subgroups	MANOVA: hip extension, hip medial rotation, hip adduction, knee extension, knee lateral rotation, knee abduction, ankle extension moments; descriptive discriminant analysis	Sig. group difference, separating variables: Ankle extension: FRW > FRM & SOW

CHAPTER 3: RESULTS OF SINGLE –LEG SQUATS

Demographics

Forty-two Division I soccer and basketball athletes (21 women, 21 men) participated in this study (Table 3). In the demographic categories of height (t_{40}=3.32, *P*=.002) and weight (t_{40}=3.20, *P*=.003), men were significantly greater than women(Table 4).

Table 3. Sex and sport breakdown of Subjects (42 total: 21women, 21 men)

Freshman Women	
Soccer Players	8
Basketball Players	3
Sophomore Women	
Soccer Players	4
Basketball Players	6
Freshman Men	
Soccer Players	13
Basketball Players	2
Sophomore Men	
Soccer Players	2
Basketball Players	4

Table 4. Demographic data (mean ± standard deviation) of subjects

Variable	Men	Women
Age	18.71 ± .90	18.48 ± .60
Height, cm*	184.08 ± 9.87	173.61 ± 10.54
Weight, kg*	78.36 ± 11.34	67.77 ± 10.07

* Indicates significant difference between men and women

Single-leg Squat

Men versus Women

Squat Characteristics

Despite the men being significantly taller on average by 11 cm, men and women both squatted equal depths (t_{40}=1.59, *P*=.119). When, however, squat depth was normalized to height, both groups squatted equal percentages of their height (t_{40}=1.10, *P*=.208). Subjects performed each squat repetition in about 1.6 seconds, with no significant difference between groups (t_{40}=1.67, *P*=.103). The women, however, used an equal percentage of the cycle for decent and ascent phases of their squats, whereas the men reached maximum squat depth significantly later in the cycle (t_{40}=4.92, *P*<.001). For normalized (COP) trajectory distance there was no significant interaction between sex and direction ($F_{1,40}$=.16, *P*=.690). There was a sex main effect ($F_{1,40}$=9.11, *P*=.004) with the men having significantly greater COP trajectory distance than the women. A direction main effect ($F_{1,40}$= 291.90, *P*<.001) revealed anterior/posterior trajectory distance being significantly greater than medial/lateral distance (Table 5).

Table 5. Single-leg squat characteristics

Variable	Men	Women
Squat Depth, m	.19 ± .04	.17 ± .05
Depth as % Height	11.26 ± 2.40	10.35 ± 2.98
Repetition Time, sec	1.64 ± .15	1.57 ± .13
% Cycle of Max Depth*	55.47 ± 3.80	50.60 ± 2.46
Normalized COP Trajectory Distance†‡	.09 ± .003	.07 ± .003
Anterior/Posterior, m	.10 ± .02	.09 ± .02
Medial/Lateral, m	.07 ± .01	.05 ± .01

* Indicates significant difference
† Indicates significant sex main effect; men > women
‡ Indicates significant direction main effect; anterior/posterior > medial/lateral

Peak Angles

Results of the peak angles attained during the squats only revealed one significant sex-related difference (Table 6). The women exhibited a significantly greater peak lateral knee rotation angle than the men (t_{40}=5.90, P<.001). When the peak knee, hip and trunk flexion angles were collapsed across sex, a significant joint main effect ($F_{2,80}$ = 202.70, P=<.001) was revealed with Tukey post hoc analysis (Tukey HSD= 7.9, P<.05) identifying significantly greater knee flexion than the hip, which in turn was significantly greater than the trunk.

Table 6. Peak angles (mean ± standard deviation) in degrees attained during the single leg squats. Negative values indicate flexion, abduction and lateral rotation.

Variable	Men	Women	*P* Values
Hip Adduction	10.7 ± 11.2	13.0 ± 8.4	.462
Hip Medial Rotation	6.1 ± 10.7	3.5 ± 7.8	.370
Knee Abduction	-3.3 ± 5.5	-3.6 ± 7.9	.871
Knee Lateral Rotation*	3.8 ± 4.9	-4.3 ± 3.9	<.001
Flexion†			
Trunk	-12.7 ± 12.6	-6.8 ± 15.6	
Hip	-59.1 ± 15.1	-60.6 ± 22.0	
Knee	-73.4 ± 13.0	-71.2 ± 11.3	

* Indicates significant difference between men and women
†Indicates significant joint main effect; knee > hip > trunk

Angular Distance

The sex by joint ANOVAs conducted on the angular distance variables did not reveal any interactions for abduction/adduction ($F_{2,39}$= .66, P= .530) or rotation ($F_{2,39}$=1.04, P=.360) (Table 7). There were also no sex related differences for abduction/adduction ($F_{1,40}$=.18, P=.680) or rotation distances ($F_{1,40}$=.31, P=.580). A significant joint main effect for adduction/abduction ($F_{2,80}$=9.74, *P*=.024) was identified. Tukey post hoc analyses (Tukey HSD= 4.66, *P*<.05) identified greater knee and hip adduction/abduction angular distance compared to the trunk. In a similar manner, a joint main effect for rotation angular distance ($F_{2,80}$=34.80, *P*<.001) was revealed. Greater rotation angular distance occurred at the hip compared to the knee, both of which were greater than the trunk (Tukey HSD=3.24, P<.05).

Table 7. Total angular distance (mean ± standard deviation) in degrees used performing single-leg squats

Variable	Men	Women
Abduction/Adduction*		
Trunk	17.4 ± 7.5	16.9 ± 9.0
Hip	27.4 ± 10.4	24.1 ± 9.6
Knee	21.3 ± 10.7	22.6 ± 11.5
Rotation†		
Trunk	14.9 ± 7.0	14.4 ± 5.8
Hip	24.5 ± 6.1	27.1 ± 8.8
Knee	21.3 ± 9.7	21.6 ± 7.6

*Indicates significant joint main effect; hip and knee > trunk
†Indicates significant joint main effect; hip > knee > trunk

Freshman Men versus Women Subgroups

Squat Characteristics

In the comparison of the freshman men to the two women subgroups, the percent of the cycle to maximum depth (F_2=14.53, *P*<.001) was the only squat characteristic in which a significant difference was revealed. Tukey post hoc revealed both the freshman women and sophomore women used more equal parts of the squat for ascent and descent, whereas, the freshman men reached maximum squat depth about 5% later (Tukey

HSD=.822, *P*<.05). For normalized COP trajectory distance, there was no significant interaction between group and direction ($F_{2,33}$=.11, *P*=.90). There was a group main effect ($F_{2,33}$=3.30, *P*=.049) with the freshman men having significantly greater normalized COP trajectory distance than the sophomore women (Tukey HSD=.011, *P*<.05). A direction main effect was also revealed ($F_{1,33}$=238.10, *P*<.001) with anterior/posterior distance being significantly greater than medial/lateral distance (Table 8).

Table 8. Single-leg squat characteristics (mean ± standard deviation)

Variable	Freshman Men (n=15)	Freshman Women (n = 11)	Sophomore Women (n=10)
Squat Depth, m	.19 ± .04	.17 ± .05	.17 ± .04
Depth as % Height	11.06 ± 2.19	10.41 ± 3.49	10.26 ± 2.5
Repetition Time, sec	1.67 ± .16	1.60 ± .15	1.53 ± .10
% Cycle of Max Depth*	55.8 ± 3.26	50.27 ± 2.85	50.97 ± 2.04
Normalized COP Distance†‡	.08 ± .003	.07 ± .004	.07 ± .004
Anterior/Posterior, m	.10 ± .02	.09 ± .02	.09 ± .01
Medial/Lateral, m	.06 ± .01	.06 ± .01	.05 ± .09

*Indicates significant differences;men > freshman and sophomore women
†Indicates significant group main effect; freshman men > sophomore women
‡Indicates significant direction main effect; anterior/posterior > medial/lateral

Peak Angles

ANOVA results revealed a significant group difference for peak knee lateral rotation angle (F_2=13.37, *P*<.001) (Table 9) only. Tukey post hoc indicated the freshman women and sophomore women both had greater knee lateral rotation peak angle than the freshman men (Tukey HSD=.829, *P*<.05). For peak flexion, there was no significant interaction or sex main effect as evidenced by the group by joint ANOVA, however, there was a significant joint main effect ($F_{3,31}$=451.5, *P*<.001). Tukey post hoc revealed peak knee flexion angle greater than hip, which in turn were both greater than the peak trunk flexion angle (Tukey HSD= 9.9, *P*<.05).

Table 9. Peak angles (mean ± standard deviation) in degrees attained during the single leg squats. Negative values indicate flexion, abduction and lateral rotation.

Variable	Freshman Men	Freshman Women	Sophomore Women
Hip Adduction	10.8 ± 13.1	13.0 ± 8.5	13.0 ± 8.6
Hip Medial Rotation	6.9 ± 11.9	2.9 ± 8.4	4.0 ± 7.5
Knee Abduction	-2.8 ± 5.9	-1.7 ± 7.7	-5.8 ± 7.8
Knee Lateral Rotation†	3.9 ± 5.6	-3.8 ± 3.7	-4.9 ± 4.3
Flexion*			
Trunk	-8.6 ± 11.0	.3 ± 12.8	-14.5 ± 15.3
Hip	-58.2 ± 12.1	-61.9 ± 23.01	-59.2 ± 21.9
Knee	-71.0 ± 13.23	-69.5 ± 11.6	-73.0 ± 11.3

*Indicates significant joint main effect; knee>hip>trunk
†Indicates significant difference freshman and sophomore women > freshman men

Angular Distances

There were no significant sex by joint interactions for either abduction/adduction ($F_{4,66}$=5.30, *P*=.720) or rotation angular distance ($F_{4,66}$=1.48, *P*=.230) (Table 10). There were also no group related differences for abduction/adduction ($F_{1,33}$=.45, *P*=.640) or rotation distances ($F_{1,33}$=.72, *P*=.490). Results did reveal a joint main effect for abduction/adduction angular distance (F_2=7.98, *P*=.001). Tukey post hoc revealed greater hip abduction/adduction angular distance than trunk, but no significant differences between hip and knee or knee and trunk abduction/adduction angular distances (Tukey HSD=5.5, *P*<.05). In a similar manner, a significant joint main effect was also revealed for rotation angular distance (F_2=36.60, *P*<.001), with greater hip rotation angular distance than knee, both of which were greater than trunk rotation angular distance (Tukey=3.7, $P<.05$).

Table 10. Total angular distance (mean ± standard deviation) in degrees used performing single-leg squats

Variable	Freshman Men	Freshman Women	Sophomore Women
Abduction/Adduction*			
Trunk	16.7 ± 7.7	19.1 ± 11.4	14.4 ± 4.8
Hip	27.8 ± 10.8	24.2 ± 10.8	23.9 ± 8.7
Knee	23.3 ± 11.7	23.4 ± 12.8	21.7 ± 10.5
Rotation†			
Trunk	13.1 ± 5.4	14.6 ± 7.5	14.1 ± 7.5
Hip	24.2 ± 5.6	24.3 ± 5.4	30.2 ± 10.9
Knee	23.0 ± 11.1	21.1 ± 4.6	22.7 ± 5.0

*Indicates significant joint main effect; hip>trunk
†Indicates significant joint main effect; hip>knee, trunk

CHAPTER 4: DISCUSSION OF SINGLE-LEG SQUATS

Single-Leg Squats

Men versus Women

We hypothesized that there would be significant joint kinematic differences between sexes while performing the single-leg squats, especially in hip adduction, knee abduction, and hip and knee rotation. In light of previous research reporting sex related kinematic differences during squats[23] and other similar activities,[14, 16-19, 22, 23, 25, 33] it is surprising that few sex related differences were revealed in the current investigation.

Although our single-leg squat methods were similar to Zeller et al,[23] there were several research design related differences that must be considered when comparing the results of the two studies. First, Zeller et al. had 18 subjects (nine men, nine women) compared to the 42 subjects (21 men, 21 women) included in the current study. Additionally, Zeller et al used subjects from a variety of sports with no focus on matching the sports between sexes. In contrast, we used 42 subjects whom participated in only soccer or basketball. The current study also excluded athletes whom had sustained a major lower extremity injury in the past 12 months, whereas, Zeller et al. only restricted injuries of the hip and knee.[23] Our rationale for the more stringent exclusion criteria was based on the widely accepted idea that the increased ACL injury rates in women are likely due to difference in execution of tasks throughout the lower extremity, not solely at the knee.[23, 25]

In addition to considering kinematic differences in squat execution at the trunk, hip, and knee joints, we also wanted to consider sex related differences in depth, the time to perform each squat, and the timing of the ascent-descent. Similar to Zeller et al,[23] we asked participants to squat down as far a possible. The men and women reached equivalent squat depths, despite the men being significantly taller. Further, both groups squatted equal depths when expressed as a percentage of their body height. This may represent a predetermined depth in relationship to one's height in which one can lower themself before loss of balance. Zeller et al. directed subjects to perform one squat within a five second period, however, they did not report the pace which athletes actually performed the squats.[23] We asked subjects to perform the squat at a rate of one squat per two seconds, reaching maximum and minimum heights each second in pace with an acoustic metronome. On average, both sexes performed the squats in just over 1.5 seconds. When the timing of the descent-ascent transition was considered, the women executed the squats with equal percent to the decent and ascent phase. The men however, used approximately 55% of the squat to descend and only 45% to elevate themselves. This could represent the eccentric descent being more essential to control to prevent injury, as men took greater percent of time to descend. If, in addition to constraining repetition time, we forced subjects to perform the ascent and descent in equal proportions, control of the squat would have been affected, which in turn may have produced different joint kinematic results. Although we did restrict the repetition time to allow for better analysis between subjects, restricting more variables would have made the squat less representative of how the subject truly would perform during athletic activity. We did qualitatively observe women performing the squat in an almost circular pattern, descending with increased hip adduction and knee valgus and ascending in increased hip abduction and knee varum. Although these observations were not revealed in a sex difference in the data, it does agree with observations reported by Zeller et al.[23]

We included normalized COP related dependent variables in the current investigation as an indirect variable reflecting the net motor pattern at the ankle in response to maintaining control over the TBCM. Normalized COP represents the point of application of the reactive forces under the feet.[34] Independent of direction, the men had a significantly higher total normalized COP trajectory distance. One interpretation of this result may be that similar to research examining COP trajectories during double leg stance in Parkinson's patients,[34] the significantly less distance by the women may represent tighter control over the TBCM. In other words, the men may have been better able to control TBCM movement within their limits of stability and therefore did not constrict the normalized COP trajectory to a limited region as the women. For all subjects, anterior/posterior COP trajectory distance was significantly greater than the medial/lateral direction. Motion occurs mainly in the sagittal plane during a squat, which would suggest more anterior/posterior trajectory distance as the TBCM adjusts with flexion of the knee. Also, the body will try to keep the TBCM centralized to prevent loss of balance. The length of the foot is greater than the width, so this also could suggest there being more anterior/posterior trajectory distance because it is influenced by there being more length before loss of balance compared to medial/lateral direction.

Zeller et al. concluded from their results that women use biomechanics during a single-leg squat that could increase the strain on the ACL compared to men.[23] They reported significant differences in range of motion between men and women for ankle dorsiflexion, supination and pronation, knee varus and valgus, hip flexion, extension, adduction and external rotation, and trunk flexion. It was difficult to determine their operational definitions of each of these motions.

Peak flexion of the trunk, hip and knee were analyzed because these motions are the primary contributors to squat execution. Hip adduction and medial rotation, and knee abduction and lateral rotation must also occur during squat performance secondary to joint arthrokinematics and need to control the TBCM over a narrow base of support. Thus, the hip adduction and medial rotation[23], and knee abduction[2, 16, 19] and lateral rotation peak angles[23] were analyzed in addition to the flexion angles[2, Salci Y, 2004 #14, 16, 22, 25, 35] because of their suggested influence in ACL injuries.[23] Surprisingly, and in contrast to Zeller et al, there were no sex differences for any of the peak angles except for knee lateral rotation. The women reached higher peak knee lateral rotation, whereas the peak average knee rotation angle for the men remained as medial rotation. With greater knee lateral rotation, there could be abnormal forces sustained at the knee, and possibly on the ACL. Women land in more erect postures with decreased knee flexion, which may not allow for optimal compensation of the hamstrings in preventing anterior translation. [22] It is noted though that there is not increased knee abduction in the women that accompanies the lateral rotation.

Peak angles and angular distances were both included in the current study. Peak angles are representative of the maximum joint movement in a particular direction. Angular distances reflect how much total motion occurred in a given direction during the squat.[14, 17] By analyzing both variables, we felt there would be a better identification of differences and a more thorough understanding of the movement.

To achieve maximum squat depth, our results suggest that for both men and women the knee makes significantly greater contribution, followed by the hip compared to the trunk. The subjects were instructed to squat down as far as they could without losing their balance. With these instructions, the subjects mainly use flexion at the knee to achieve maximal decent. It would be interesting in future research to determine the timing of the knee, hip, and trunk flexion patterns. For example, do peak knee and hip flexion angles occur simultaneously or is a certain degree of knee flexion attained before initiating hip flexion?

The current study calculated the rotation and abduction/adduction angular distances at the trunk, hip, and knee. We found no sex related differences for the angular distances of adduction/abduction or rotation for the trunk, hip, or knee. The only significant differences we found were joint main effects for both adduction/abduction and rotation. Both men and women used significantly greater knee and hip adduction/abduction angular distances than lateral trunk flexion. Both men and women also performed the squats with significantly greater rotation angular distances at the hip than at the knee, but used more at the knee than at the trunk. The hip has more available range of motion for these actions than both the knee and trunk, and these data confirm that more of the available motion is actually used at this joint. With no sex differences for knee total adduction/abduction distance or rotation, it would suggest women were able to control these motions to keep them comparable to the men. These data do not support previous studies reporting sex differences.[23]

The single-leg squat has been used to assess general leg strength and muscle endurance.[36] The Trendelenburg test is used clinically to assess hip abductor weakness and is a component of the single-leg squat.[36] It is typically believed a positive Trendelenburg test suggests hip abductor weakness, leading to increased hip adduction and increased valgus angles at the knee.[23] In a recent study investigating the single-leg squat, results revealed that among active men and women, hip abduction maximum strength tests did not have a significant correlation with hip adduction during both the Trendelenburg test or single-leg squat. It should be noted that subjects performed single-leg squats in the DiMattia et al. study with a physical block preventing them from going below sixty degrees of knee flexion and they held their hands together straight out in front of them.[36] This is ten degrees less knee flexion that the subjects in the current study self-selected to reach. With the pace and depth restrictions of the task, subjects may have been able to perform the task with more control, and indirectly, with less hip adduction. With subjects having their arms flexed straight out in front of them, with hands clasped, this might have changed the execution of the task. It brings the TBCM forward and might allow for altered hip compensation. Results from the current study do not suggest a lack of adduction/abduction control at the hips or that women were less able to control this motion because of weaker hip abductors.

Clinically, there has been much focus on sex differences and how women's training could be altered to improve their mechanics so they resemble men's mechanics, possibly decreasing risk of ACL injury. We interpret the results of our study to suggest that our sample of freshman and sophomore women have had adequate training have similar mechanics to freshman men, or that the single leg squat may not be a good assessment for revealing apparent sex related differences. One area of future interest is more exploration of the percent time maximal squat depth was attained. Men used more of the squat for the descent compared to the women. Thus, a clinical area of focus could be not changing the mechanics of the squat, but possibly having women focus on controlling the speed in which they lower themselves. Controlling the land and lowering the whole body could be just as important in injury rate differences as the specific mechanics. There was no difference in the speed of groups performing the task as a whole, so encouraging women to extend the percent of the descent and decreasing the percent of the ascent could be an area for further research.

In conclusion, the current study found there were not the significant sex differences while performing a single-leg squat that were hypothesized. With the considerable differences in the results between the current study and the study by Zeller et al., further research should be considered to continue to understand between sex differences in the execution of tasks and if this contributes to ACL injury.

Men versus Women Subgroups

The two women groups were compared to the freshman men group and between each other. Sophomore men were excluded from this comparison because of the low subject number (n=6) leading to very unbalanced sample sizes. We wanted to compare the subgroups because we hypothesized that although both the freshman and sophomore women would perform differently from the freshman men, the sophomore women would have results nearing those of the men after their completion a year of collegiate athletic training. Many plyometric and weight training programs have been proposed that report decreased knee injuries[26, 28] and decreased knee torques.[37] We were interested examining if there would be changes just with the normal training that collegiate athletes are exposed to and whether it would lead to less risky ACL positions.

Like the overall comparison between men and women, both woman subgroups performed the squat ascent and descent in about equal parts, whereas the freshman men used over 55% for the descent of the squat and less than 45% to ascend. It is of interest that the normalized COP trajectory distance was greater for the freshman men compared to sophomore women but not between freshman men and freshman women. From our previous discussion about possible sex differences in normalized COP trajectory distance, this could reflect sophomore women needing to be more focused to execute the same task the freshman men could perform with less focus and resulting COP trajectory distance. It goes against our hypothesis that the sophomore women would be different from the freshman men, and not the freshman women.

For the peak angles and total angular distances, there were no significant differences between any of the subgroups. This indicates that not only does sex not affect these squat variables, but was also not affected by whether the women were freshman or sophomores. It could also be noted that between the freshman and sophomore women, peak trunk flexion was the only significantly different factor. Sophomore women reached greater trunk flexion angles, which were more representative of the men. Differences in trunk flexion could affect the hamstrings and their ability to restrict anterior tibial translation.

CHAPTER 5: RESULTS OF SINGLE-LEG LAND

Single-leg land

Men versus Women

Single-leg Land Characteristics

For the double-leg vertical jump with single-leg land characteristic categories of peak vertical ground reaction force (vGRF) (t_{40}=4.93, P<.001), normalized vGRF (t_{40}=2.77, P=.009), flight time (t_{40}=2.23, P=.032), and total body center of mass (TBCM) velocity at ground contact (GC) (t_{40}=6.73, P<.001) men were significantly greater than women (Table 11). Even with these differences, there were no significant differences in the landing phase time (t_{40}=.80, P=.430).

Table 11. Single-leg land characteristics (mean ± standard deviation)

Variable	Men (n=21)	Women (n=21)
Peak vGRF, N *	3452.4 ± 721.9	2565.5 ± 399.6
Norm Peak vGRF, N/kg *	44.0 ± 5.6	38.4 ± 7.4
Flight time, s *	.51 ± .14	.44 ± .04
Landing phase, s	.21 ± .08	.20 ± .05
TBCM vel @ GC, m/s *	2.6 ± .26	2.1 ± .20

* Indicates significant difference between men and women

Peak Moments Normalized to Body Mass

Peak NJM were normalized to both body mass and momentum at GC and subjected to a multivariate analysis. Multivariate analysis included peak extension moments at the ankle, knee, and hip; peak abduction and lateral rotation moment at the knee; and peak adduction and medial rotation moments at the hip (Table 10). A

MANOVA revealed a significant difference between the men and women ($F_{7,34}$=3.06, *P*=.013) for this set of variables. Descriptive discriminant analysis was used for follow-up analysis. The structure matrix demonstrated that the men and women were separated by hip medial rotation, knee lateral rotation, and hip extension peak NJM (Table 13). The men had greater peak NJM for all three of these variables.

Table 12. Peak net joint moments normalized to body mass (Nm/kg). Negative values indicate lateral rotation and abduction.

Variable	Men	Women
Hip Extension	4.49 ± 2.38	3.22 ± 1.19
Hip Medial Rotation	1.11 ± .66	.70 ± .29
Hip Adduction	2.15 ± 1.18	1.89 ± 1.33
Knee Extension	2.37 ± 1.38	1.93 ± 1.09
Knee Lateral Rotation	-.85 ± .52	-.52 ± .44
Knee Abduction	-.81 ± .57	-.68 ± .38
Ankle Extension	2.13 ± .89	2.19 ± .85

Table 13. Structure matrix for peak net joint moments normalized to body mass

Variable	Function 1
Hip Medial Rotation	-.528*
Knee Lateral Rotation	.438*
Hip Extension	-.437*
Knee Extension	-.231
Knee Abduction	.177
Hip Adduction	-.136
Ankle Extension	.038

*Separating variables > absolute .40

Peak Net Joint Moments Normalized to Momentum at GC

The MANOVA for peak NJM normalized to momentum at GC revealed no significant differences between the men and women ($F_{7,34}$=2.22, *P*=.057) (Table 14).

Table 14. Peak net joint moments normalized to momentum at GC (Nm/Mv). Negative values indicate extension, adduction and medial rotation.

Variable	Men	Women
Hip Extension	-.02 ± .008	-.02 ± .008
Hip Medial Rotation	-.006 ± .003	-.005 ± .002
Hip Adduction	-.011 ± .005	-.014 ± .010
Knee Extension	-.012 ± .007	-.014 ± .009
Knee Lateral Rotation	.004 ± .002	.004 ± .003
Knee Abduction	.004 ± .003	.005 ± .003
Ankle Extension	-.011 ± .005	-.016 ± .008

Men versus Women Subgroups

Characteristics

There were significant differences between the groups for peak vGRF (F_2=8.78, *P*=.001), normalized peak vGRF (F_2=3.51, *P*=.041) and TBCM velocity at GC. Tukey post hoc revealed the men had greater peak vGRF than the freshman women and sophomore women (HSD=.583, *P*<.05), but no difference between the freshman women and sophomore women. Tukey post hoc also revealed the freshman men had significantly greater normalized peak vGRF than the sophomore women, but no significant difference between the freshman women and the freshman men or sophomore women (Tukey HSD=.052, *P*<.05). The freshman men also had greater TBCM velocity at GC than both the freshman women and sophomore women. There were no significant differences between the women subgroups for TBCM velocity at GC (Tukey HSD= .161, *P*<.05). There were no significant differences between the groups for flight time (F_2=.99, *P*=.380), or landing phase (F_2=.58, *P*=.568) (Table 15).

Table 15. Single-leg land characteristics (mean ± standard deviation)

Variable	Freshman Men (n=15)	Freshman Women (n=11)	Sophomore Women (n=10)
Peak vGRF, N*	3365.6 ± 765.8	2451.3 ± 454.1†	2691.2 ± 303.8‡
Norm Peak vGRF, N/kg*	44.2 ± 5.2	39.2 ± 8.4	37.5 ± 6.4‡
Flight time, s	.49 ± .16	.43 ± .03	.46 ± .11
Landing phase, s	.22 ± .09	.19 ± .05	.21 ± .05
TBCM vel @ GC, m/s*	2.5 ± .24	2.0 ± .13†	2.2 ± .23‡

*Indicates significant differences between groups
†Indicates significant difference between freshman men and freshman women
‡Indicates significant difference between freshman men and sophomore women

Peak Net Joint Moments Normalized to Body Mass

Table 16. Peak net joint moments normalized to body mass (Nm/kg). Negative values indicate lateral rotation and abduction.

Variable	Freshman Men*	Freshman Women*	Sophomore Women
Hip Extension	4.45 ± 2.33	2.90 ± 1.04	3.57 ± 1.31
Hip Medial Rotation	1.22 ± .73	.69 ± .38	.70 ± .16
Hip Adduction	2.11 ± .85	1.83 ± 1.44	1.96 ± 1.30
Knee Extension	2.44 ± 1.26	1.93 ± 1.06	1.93 ± 1.17
Knee Lateral Rotation	-.86 ± .41	-.42 ± .27	-.63 ± .57
Knee Abduction	-.86 ± .55	-.83 ± .34	-.51 ± .36
Ankle Extension	2.16 ± .56	2.66 ± .70	1.67 ± .69

*Indicates significant differences between freshman men and freshman women

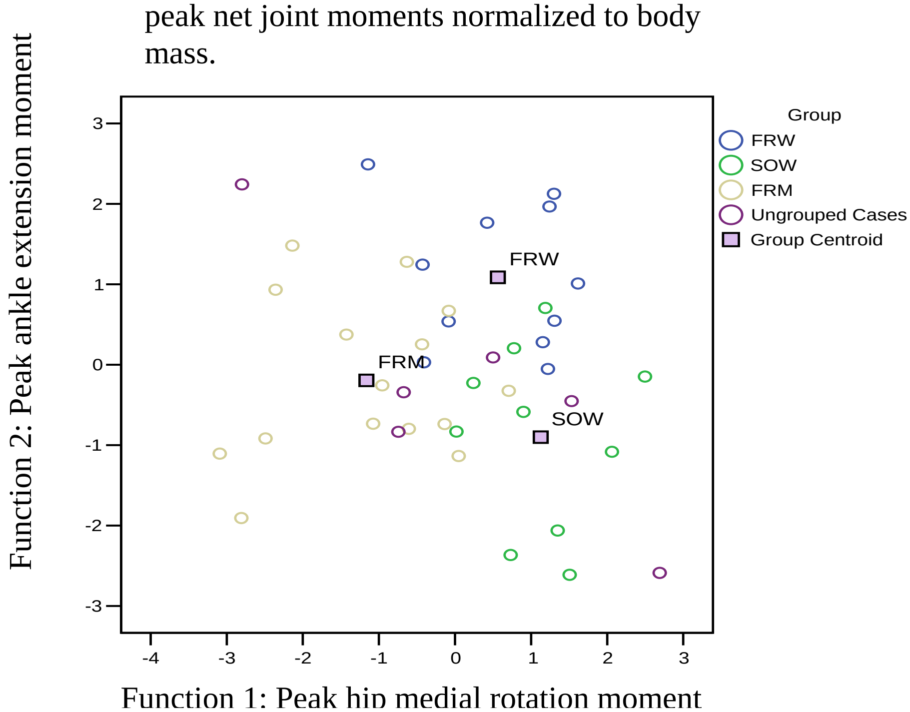
A MANOVA showed significant differences between the groups ($F_{14,56}$=3.42, *P*=.001) for peak NJM normalized to body mass (Table 14). Follow-up discriminant analysis showed for function one, groups were separated by peak hip medial rotation NJM only (Table 17). Canonical discriminant functions revealed the freshman men had greater peak hip medial rotation NJM than both the freshman women and sophomore women, but no difference between the freshman women and sophomore women (Figure 1).

Table 17. Structure matrix for peak net joint moments normalized to body mass (Function 1)

Variable	Function 1
Hip Medial Rotation	-.480*
Hip Extension	-.303
Knee Extension	-.208
Hip Adduction	-.081
Ankle Extension	-.108
Knee Lateral Rotation	.333
Knee Abduction	.252

*Indicates separating variable > absolute .40

Figure1. Canonical discriminant functions for peak net joint moments normalized to body mass.



Follow-up analysis also revealed for function two, groups were separated by peak ankle extension NJM only (Table18). Canonical discriminant functions revealed all three groups were different for ankle extension NJM, with the freshman women having greater ankle extension NJM than the freshman men, who were greater than the sophomore women (Figure 1).

Table 18. Structure matrix for peak net joint moments normalized to body mass (Function 2)

Variable	Function 2
Ankle Extension	-.750*
Knee Lateral Rotation	.342
Knee Abduction	-.291
Hip Extension	-.276
Hip Medial Rotation	-.137
Hip Adduction	-.079
Knee Extension	-.060

Peak Net Joint Moments Normalized to Momentum at GC

Table 19. Peak net joint moments normalized to momentum at GC (Nm/Mv). Negative values indicate extension, adduction, and medial rotation.

Variable	Freshman Men	Freshman Women	Sophomore Women
Hip Extension	-.022 ± .007	-.024 ± .009	-.023 ± .009
Hip Medial Rotation	-.007 ± .004	-.006 ± .003	-.005 ± .002
Hip Adduction	-.011 ± .004	-.014 ± .011	-.013 ± .009
Knee Extension	-.013 ± .007	-.016 ± .010	-.013 ± .008
Knee Lateral Rotation	.004 ± .002	.003 ± .002	.004 ± .004
Knee Abduction	.005 ± .003	.007 ± .003	.003 ± .002
Ankle Extension	-.012 ± .004	-.022 ± .007	-.011 ± .008

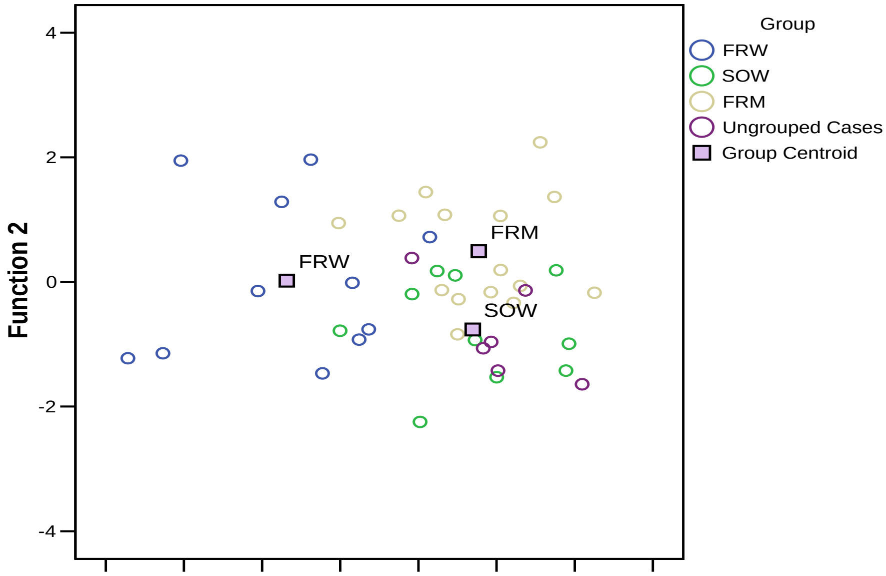
A MANOVA showed significant differences between the groups for the selected variables ($F_{14,56}$=2.67, *P*=.005) for peak NJM normalized to momentum at GC (Table 19). Follow-up discriminant analysis showed only one significant function, separating groups by peak ankle extension NJM only (Table 20). Canonical discriminant functions revealed the freshman women had greater peak ankle extension NJM than both the freshman men and sophomore women, but no difference between the freshman men and sophomore women (Figure 2).

Table 20. Structure matrix for peak net joint moments normalized to momentum at GC (function 1)

Variable	Function 1
Ankle Extension	.700*
Knee Lateral Rotation	.261
Knee Abduction	-.253
Hip Adduction	.148
Knee Extension	.121
Hip Medial Rotation	-.113
Hip Flexion	.051

*Separating variables > absolute .40

Figure 2. Canonical discriminant functions for peak net joint moments normalized to momentum at GC



Function 1: Peak ankle extension net joint moment

CHAPTER 6: DISCUSSION OF SINGLE-LEG LAND

Men versus Women

Many ACL studies have focused on biomechanical differences between men and women in executing tasks. Researchers agree that it is most likely not one variable alone that increases the chance of ACL injury in women, but a combination of variables.[17, 23, 25] While much attention has focused on kinematic differences, the current study was more interested in the peak NJM differences between the sexes. At any given instance, there are multiple moments acting on the lower extremity during the performance of athletic tasks. This was the rationale for the current study analyzing a single-leg land following a vertical jump with a multivariate analysis of the peak NJM. Studies using univariate approaches have reported women exhibiting greater peak hip extension moments,[2, 14, 33] peak knee extensor moments,[2, 14] and peak knee varus/valgus moments[2] than men during impact phase of landing. The risk for non-contact ACL injuries is associated with activities involving rotation and acceleration/deceleration with the lower extremity joints in more extended positions.[19, 25, 38] Previous research provided the rationale for including in our multivariate analysis ankle, knee, and hip extension NJM; knee abduction and lateral rotation NJM; and hip adduction and medial rotation NJM. Further, consistent with the previous literature, knee abduction was defined as the distal segment (shank) moving away from the midline placing the knee into a valgus position and hip adduction as the distal segment (thigh) moving toward the midline. The current study analyzed peak NJM for comparison to previous literature,[2, 14, 33] and because of the general assumption that ACL tears are an acute injury occurring because of one instance of acute trauma.

In the current study, there were sex differences for normalized vGRF, flight time, and TBCM velocity at GC. Greater vGRF and TBCM velocity at GC could indicate that men had greater jump heights than women, leading to greater impact forces. Alternatively, the difference in flight time and ground contact velocity could indicate that before landing, men retract their lower extremity with hip, knee, and ankle flexion in anticipation of impact absorption. Interestingly, both sexes had nearly identical impact phases. Coupled with the higher peak vGRF, this would suggest that the shock absorption impulses would be greater in the men.

Similar to previous research considering peak NJM in the lower extremity, [2, 14, 33] we normalized peak NJM to body mass to account for biomechanical differences that could be attributable to body mass differences between the sexes. When the peak NJM were normalized to body mass, there was a significant difference between the men and women with follow up analyses revealing the groups to be separated by peak hip medial rotation, knee lateral rotation, and hip extension NJM. For the three separating variables, the men had higher peak NJM than the women. These results differed from previous research[2, 14, 33] and were opposite from our hypothesis that women would have greater peak rotation moments at the hip and knee, adduction at the hip, abduction at the knee, and extension at the hip, knee and ankle compared to the men. Interpretation of these results would suggest, that when jump heights, and therefore ground contact velocity, are not controlled, such as a soccer player doing a maximum vertical jump in an attempt to head a ball, that peak hip and knee NJM and peak hip extension NJM could be the major factors that influence sex differences and possibly ACL injuries. When landing, normal shock absorption strategy involves eccentric control of ankle dorsiflexion, and knee and hip flexion. The men having greater peak hip NJM could be a result of those muscles contributing greater to the overall shock absorption strategy. Surprisingly, and in contrast to what would be expected if greater hip contributions were being made, there were no differences in knee and ankle flexion peak NJM. Increased extensor NJM at the hip might be due in part to the hamstrings being activated and working on the knee[39] and from men putting more stress on the hip than on the knee. Alternatively, the higher hip extensor NJM in the men might be a result of men having heavier upper bodies than women. Devita and Skelly reported that prior to ground contact, the hip extensor moments were working eccentrically.[39] In other words, the higher peak extensor NJM may have been the result of the hip extensors working eccentrically to control trunk flexion. The greater peak hip medial rotation NJM and peak knee lateral rotation NJM in men could represent a force dissipating mechanism at the knee that transfers some of the impact energy to other planes beyond the sagittal plane. One reason for this mechanism not being previously described may be the reduced focus that has been placed on rotation compared to flexion-extension and abduction-adduction. In landing, the hip medial rotation NJM and knee lateral rotation NJM could help with impact dissipation with the added bonus of not producing anterior knee joint shear forces that would be associated with knee extensor NJM.

Direct comparison of our results to previous literature examining sex differences in moments is difficult because of methodology differences. Decker et al[14] reported no sex moment differences during drop landings from 60 centimeter platform, whereas the current study did have sex differences. Decker et al. had subjects land on both legs, but only their dominant leg on the force plate, whereas, our subjects were landing on their dominant leg only after a 75% double-leg vertical jump. Chappell et al. reported women using knee valgus moments when landing from a 3 step approach before jumping vertically, whereas, men exhibited a varus moment.[2] In the current study, separating variables did not include knee abductor moments or hip adductor moments. This could be because our subjects were performing a purely vertical task, whereas Chappell et al's subjects had the forward approach. Further, in contrast to the current study, Chappell et al. also reported women using greater knee extension moment than men when jumping vertically.[2]

For the current study, we wanted subjects to self-select the execution of the jump and land to represent how they would land during an athletic task. The issue with this approach is that differences in ground contact velocities become inevitable. Thus, in analyzing the data we wanted to try and control for differences in jump height and velocity, so we also analyzed the peak NJM normalized to momentum at GC. With the peak NJM normalized to momentum at GC, while approaching significance, there were no significant sex differences. This would suggest that if the men were not landing with greater momentum (mass x velocity) that there would not be the sex differences that were identified when the peak NJM were normalized to body mass. If the jump height and ground contact velocity are controlled (i.e., drop landing) or are identical for both men and women, we would expect the peak NJM normalized to body mass to be similar. An example of this might be athletes trying to land following a rebound off the basketball rim. The height is set; therefore the velocity at impact and NJM would be similar.

In a study investigating the use of an overhead goal in a drop landing followed by take-off to maximum vertical jump, there was only a difference in NJM at the knee between trials with and without the overhead goal. It was reported that during the take-off phase, the knee extensor NJM was greater with the use of the goal compared to subjects jumping as high as they felt they could.[33] Subjects also jumped significantly higher with the use of the overhead goal.[33] Because our task involved an overhead goal (75% maximum jump height) this could suggest that the mechanics recorded in this study could be different from athletes landing during athletic tasks without overhead goals

Men versus subgroups

Men and women were further separated into freshman women, sophomore women, and freshman men for further comparison. Sophomore men were excluded from this comparison because of the low subject number (n=6). It was assumed that with this low subject number, they could be excluded and the freshman men would still represent the general results of all the men while making the group numbers comparable. We wanted to compare the subgroups because we hypothesized that sophomore women would have results nearing those of the men because they have completed a year of collegiate athletic training including weight training, whereas, the freshman women would execute tasks differently than all other groups. Many plyometric and weight training programs have been proposed that report decreased knee injuries[26, 28] and decreased knee torques.[37] We were interested in examining if there would be changes just with the normal training that collegiate athletes are exposed to and whether it would lead to less ACL risky.

For single-leg landing characteristics, there were group differences for peak vGRF, normalized peak vGRF, and TBCM velocity at GC. Follow-up analyses showed that men had greater values for all three of these variables compared to both freshman women and sophomore women. There were no differences for any of the single-leg land characteristics between the freshman women and sophomore women. This supports men having greater velocities at ground contact than both groups of women that was also found in the men versus women comparison.

For multivariate analysis of NJM normalized to body mass, there was a difference for the selected variables for the groups. Peak hip medial rotation and peak ankle extension NJM were the separating variables for these groups. Freshman men exhibited greater peak hip medial rotation NJM than both the freshman and sophomore women, with no difference between the two women groups. All three groups were different for peak ankle extension NJM with freshman women having greater NJM than the freshman men, who were greater than the sophomore women. Again, men using greater peak hip medial rotation could be a force dissipating mechanism to try to prevent greater shear forces at the knee that would be associated with knee extensor NJM. The peak ankle extension NJM being a separating variable was interesting in that it was not a separating variable in the men versus women analysis. Freshman women had greater peak ankle extension NJM than the other two groups. Devita and Skelly had subjects perform a drop landing instructing them for some trials to land softly or stiffly. Stiff lands resulted in greater ankle extension moments and more energy absorption at the ankle than at the hip and knee.[39] This could support the idea that the freshman women land more stiffly and therefore have greater peak ankle extension NJM. The freshman men and sophomore women may have learned to land softer and therefore distribute the forces through the ankle, knee and hip. Devita and Skelly also speculated that the muscular system absorbed more of the body’s kinetic energy in the soft land than the stiff, therefore when the freshman women land in a stiffer position, bone and ligaments, such as the ACL and other structures will experience greater impact stresses.[39]

In the men versus women (sex) comparison, the separating factors were hip medial rotation, knee lateral rotation and hip extension NJM. This represents that when normalized to body mass, freshman and sophomore women had similar NJM of hip medial rotation, but different peak ankle extension NJM, which was not revealed in the pure men versus women analysis. The sophomore women having completed a full year of collegiate athletic training including weight training could influence differences between the freshman and sophomore women. It was hypothesized that a year of training could lead to alterations in the sophomore women's biomechanics that would resemble closer to those of the men's biomechanics.

With the peak NJM normalized to momentum at GC, slightly different results were revealed than when the NJM were only normalized to body mass. Multivariate analysis revealed significant difference between the groups, but the only separating variable was ankle extension NJM. The freshman women had greater peak ankle extension NJM than both the freshman men and sophomore women, but there was no difference between the freshman men and sophomore women. Hip medial rotation NJM were not a separating variable when the NJM were normalized to momentum at GC, as it was when normalized to body mass.

We hypothesized that differences in knee NJM would be revealed, with the greatest differences existing between the freshman men and women. Peak ankle extension NJM were a separating variable when normalized to body mass and momentum at GC. Although it was surprising that the common separating variable was at the ankle, this still may support freshman women having different mechanics than the sophomore women because the sophomores have completed a year of athletic participation. Over 75% of the freshman women subjects questioned reported never participating in a regular, intense weight-lifting program. As Division-I athletes, it is likely that they had participated in regular cardiovascular and sport specific training. We are assuming that the differences between the freshman and sophomore women are a result of the year of experience and weight training that the sophomore women have completed. Again, greater peak ankle extension NJM might be indicative of landing stiffer with more force absorption having to occur at the knee and hip.

It was interesting that the differences revealed in the men versus woman subgroup analysis directed more attention to the peak ankle extension NJM which were not a separating variable in the men versus women comparison. In looking at the raw data, it is interesting for peak ankle extension NJM, freshman women had values greater than men, but sophomore women had lower NJM so they averaged out resulting in women means similar to those of the men and making peak ankle extension NJM not a separating variable. Possible differences between college levels or experience should be considered in future studies comparing sexes so these possible differences are not overlooked.

A limitation of the men versus woman subgroups is the group size. Freshman women (11), sophomore women (10) and freshman men (15) were analyzed for this further breakdown. Although the results suggest interesting and relevant points to attention, further research with more subjects in the individual groups needs to be undertaken to confirm these preliminary data.

Conclusion

Clinically, our results this could suggest that when analyzing landing biomechanics, there are differences between normalizing NJM to body mass and normalizing them to momentum at GC. A Men versus women comparison revealed separating variables of peak hip medial rotation, peak knee lateral rotation and peak hip extension NJM when normalized to body mass, but there was no sex difference when normalized to momentum at GC. For men versus woman subgroups, peak medial rotation and peak ankle extension NJM were the separating variables, but when normalized to momentum at GC peak ankle extension NJM was the only separating variable between the groups. We do not know which normalizing method produces more accurate interpretation into the true differences between the groups and feel it is an area that needs to be explored. With the results of this study and the differences found between, not only the men and women, but also between the men and women subgroups is encouraging to further research on possible effects of regular workouts to biomechanics and their possible implication to ACL injuries. This could aid in improving regular collegiate training programs to decrease ACL injuries without putting athletes in ACL jump/landing programs. It was also interesting the differences between NJM normalized to body mass and normalized to momentum at GC in how these different analyses of the same biomechanics can result in such difference outcomes on significance and on the variables that separate the groups.

REFERENCES FOR INTRODUCTION, METHODS, RESULTS & DISCUSSION

1. Bonci CM. Assessment and evaluation of predisposing factors to anterior cruciate ligament injury. *J Ath Train.* 1999;34(2):155-164.

2. Chappell JD, Yu B, Kirkendall DT, Garrett WE. A comparison of knee kinetics between male and female recreational athletes in stop-jump tasks. *Amer J Sports Med.* 2002;30(2):261-267.

3. Arendt EA, Agel J, Dick R. Anterior cruciate ligament injury patterns among collegiate men and women. *J Ath Train.* 1999;34(2):86-92.

4. Ireland ML. Anterior cruciate ligament injury in female athletes: epidemiology. *J Ath Train.* 1999;34(2):150-154.

5. Loudon JK, Jenkinds W, Loudon KL. The relationship between static posture and ACL injury in female athletes. *J Orthop Sports Phys Ther.* 1996;24:91-97.

6. Woodford-Rodgers B, Cyphert L, Denegar CR. Risk factors for anterior cruciate ligament injury in high school and college athletes. *J Athl Train.* 1994;29:343-346.

7. Anderson AF, Dome DC, Gautam S, Awh MH, Rennirt GW. Correlation of anthropometric measurements, strength, anterior cruciate ligament size, and intercondylar notch characteristics to sex differences in anterior cruciate ligament tear rates. *Amer J Sports Med.* 2001;29(1):58-65.

8. Beckett ME, Massie Dl, Bowers KD, Stoll DA. Incidence of hyperpronation in the ACL injured knee: a clinical perspective. *J Ath Train.* 1992;27:58-62.

9. Huegel M, Meister K, Rolle G, Indelicato PA, Hartzel J. The influence of lower extremity alignment in the female population on the incidence of noncontact ACL tears. Paper presented at: 23rd Annual Meeting of the American Orthopaedic Society for Sports Medicine, 1997; Sun Valley, ID.

10. Belanger MJ, Moore DC, Crisco JJ, Fadale PD. Knee laxity does not vary with the menstrual cycle, before or after exercise. *Amer J Sports Med.* 2004;32(5):1150-1157.

11. Heitz NA, Eisenman PA, Beck CL, Walker JA. Hormonal changes throughout the menstrual cycle and increased anterior cruciate ligament laxity in females. *J Ath Train.* 1999;34(2):144-149.

12. Wojtys EM, Huston LJ, Lindenfeld TN, Hewett TE, V.H. Greenfield ML. Association between the menstrual cycle and anterior cruciate ligament injuries in female athletes. *Amer J Sports Med.* 1998;26(5):614-620.

13. Wojtys EM, Ashton-Miller JA, Huston LJ. A gender-related difference in the contribution of the knee muscularture to sagittal-plane shear stiffness in subjects with similar knee laxity. *J Bone Joint Surg.* 2002;84(1):10-16.

14. Decker MJ, Torry MR, Wyland DJ, Sterett WI, Steadman JR. Gender differences in lower extremity kinematics, kinetics and energy absorption during landing. *Clin Biomech.* 2003;18:662-669.

15. Orchard J. Is there a relationship between ground and climatic conditions and injuries in football? *Sports Med.* 2002;32(7):419-432.

16. Malinzak RA, Colby SM, Kirkendall DT, Yu B, Garrett WE. A comparison of knee joint motion patterns between men and women in slected athletic tasks. *Clin Biomech.* 2001;16:438-445.

17. Lephart SM, Ferris CM, Riemann BL, Myers JB, Fu FH. Gender differences in strength and lower extremity kinematics during landing. *Clin Orthop Rel Res.* 2002;401:162-169.

18. Salci Y, Kentel BB, Heycan C, Akin S, Korkusuz F. Comparison of landing maneuvers between male and female college volleyball players. *Clin Biomech.* 2004;19:622-628.

19. Ford KR MG, Hewett TE. Valgus knee motion during landing in high school female and male basketball players. *Med Sci Sports Exerc.* 2003;35(10):1745-1750.

20. Hewett TE, Myer GD, Ford KR. Decrease in neuromuscular control about the knee with maturation in female athletes. *J Bone Joint Surg.* 2004;86(8):1601-1608.

21. Colby S, Francisco A, Yu B, Kirkendatt D, Finch M, Garrett Jr. W. Electromyographic and kinematic analysis of cutting maneuvers. *Amer J Sports Med.* 2000;28(2):234-245.

22. Fagenbaum R, Darling WG. Jump landing strategies in male and female college athletes and the implications of such strategies for anterior cruciate ligament injury. *Amer J Sports Med.* 2003;31(2):233-240.

23. Zeller BL, McCrory JL, Kibler WB, Uhl TL. Differences in kinematics and electromyographic activity between men and women during the single-legged squat. *Amer J Sports Med.* 2003;31(3):449-456.

24. Hollman JH DR, Van Dillen LR, Matava MJ. Gender differences in surface rolling and gliding kinematcis of the knee. *Clin Orthop Rel Res.* 2003;413:208-221.

25. James CR, Sizer PS, Starch DW, Lockhart TE, Slauterbeck J. Gender differences among sagittal plane knee kinematic and ground reaction force characteristics during a rapid sprint and cut maneuver. *Res Quart Exerc Sport.* 2004;75(1):31-39.

26. Hewett TE, Lindenfeld TN, Riccobene JV, Noyes FR. The effect of neuromuscular training on the incidence of knee injury in female athletes. *Amer J Sports Med.* 1999;27(6):699-713.

27. Hewett TE, Stroupe AL, Nance TA, Noyes FR. Plyometric training in female athletes. *Amer J Sports Med.* 1996;24(6):765-773.

28. Heidt RS, Sweeterman LM, Carlonas RL, Traub JA, Tekulve FX. Avoidance of soccer injuries with preseason conditioning. *Amer J Sports Med.* 2000;28(5):659-662.

29. Holm I, Fosdahl MA, Friis A, Risberg MA, Myklebust G, Steen H. Effect of neuromuscular training on proprioception, balance, muscle strength, and lower limb function in female team handball players. *Clin J Sport Med.* 2004;14(2):88-94.

30. Leardini A, Catani F ea. Validation of a functional method for estimation of hip joint centre location. *J Biomech.* 1999;32:99-103.

31. Schache A, Blanch P, Rath D, Wrigley T, Bennell K. Differences between the sexes in the three-dimensional angular rotations of the lumb-pelvic-hip complex during treadmill running. *J Sports Sci.* 2003;21:105-118.

32. Robertson DGE, Caldwell GE, Hamill J, Kamen G, SN W. *Research Methods in Biomechanics*. Champaign: Human Kinetics; 2004.

33. Ford KR, Myer GD, Smith RL, Byrnes RN, Dopirak SE, Hewett TE. Use of an overhead goal alters vertical jump performance and biomechanics. *J Strengh Cond Res.* 2005;19(2):394-399.
34. van Emmerik REA, van Wegen EEH. On the functional aspects of variability in postural control. *Sport Sci Rev.* 2002;30(4):177-183.
35. Lephart SM, Abt JP, Ferris CM, et al. Neuromuscular and biomechanical characteristic changes in high school athletes: a plyometric versus basic resistance program. *Br J Sports Med.* 2005;39:932-938.
36. DiMattia MA, Livengood AL, Uhl TL, Mattacola CG, Malone TR. What are the validity of the single-leg-squat test and its relationship to ip-abduction strength? *J Sport Rehabil.* 2005;14:108-123.
37. Myer GD, Ford KR, Palumbo JP, Hewett TE. Neuromuscular training improves performance and lower-extremity biomechanics in female athletes. *J Strengh Cond Res.* 2005;19(1):51-60.
38. Rosene JM, Fogarty TD. Anterior tibial translation in collegiate athletes with normal anterior cruciate ligament integrity. *J Ath Training.* 1999;34(2):93-98.
39. Devita P, Skelly WA. Effect of landing stiffness on joint kinetics and energetics in the lower extremity. *Med Sci Sports Exerc.* 1992;24:108-115.

APPENDIX A

RESEARCH HYPOTHESIS:

1. For the single-leg squats, women will perform with significantly less hip and knee flexion, more hip adduction and medial rotation, and more knee abduction and lateral rotation.

2. While sophomore women will perform single-leg squats with significantly less hip and knee flexion, but more hip adduction, hip medial rotation, knee abduction, knee lateral rotation than the men, their performance of the task will be more similar to the men than to the freshman women.

3. We hypothesize women will perform the landing task significantly different from the men for the given set of variables of hip extension, medial rotation, and hip adduction, knee extension, lateral rotation and abduction, and ankle extension peak moments. We hypothesize that women will have greater peak moments for each of these variables than the men.

4. Again, while sophomore women will have significantly greater peak moments than the men, their execution of the task will be more similar to the men than the freshman women to the men.

LIMITATIONS:

1. No control group: The focus of the study is on an athletic population. It would likely decrease the willingness of coaches and athletes to participate if the athletes were asked not to participate in athletic activity, strength/conditioning, and training for the season.

2. Deliberate sampling: Groups were chosen and predetermined for transfer of generalization, and for the ability to compare to similar studies. Soccer and basketball are also two sports with the most documented ACL injuries.

3. Controlled setting for biomechanics testing: Although all the training and conditioning for each sport occured in their natural setting, the biomechanical testing was done in the controlled environment of a biomechanics lab at Georgia Southern University.

4. Sample size: Although forty-two subjects participated, the breakdown of groups (freshman women=11, sophomore women=10, freshman men=15, sophomore men=6) made it that we could not use the sophomore men for group analysis. These groups depended on the size of each class of freshmen and sophomores for soccer and basketball.

DELIMITATIONS:

1. Testing was done on freshman and sophomore men and women at one Division-I southeastern university.

2. Soccer and basketball were tested.

3. Subjects were not classified by sports, only by sex and class.

4. Past history of subjects’ resistance training.

ASSUMPTIONS:

1. Athletes performed at their maximum level, both during testing and during their resistance training, to ensure they benefited from the training and provided accurate biomechanical data.

2. The majority of incoming freshmen have not regularly participated in intensive resistance training prior to college.

3. Subjects gave honest responses for their medical history and understood the instructions.

4. The physical demands did not exceed those commonly experienced by Division I varsity athletes.

DEFINITIONS:

1. Freshman - subject who is in their first year of NCAA eligibility and participation with their sports team.

2. Sophomore - subject who is in their second year of NCAA eligibility and participation with their sports team.

3. Moment - the effectiveness of a force to causing rotation

4. Healthy - subject who does not currently have an injury or illness that prevents them from participating in athletic practice or competition

Landing Phase – From the time when the Vertical Ground Reaction Force indicates the subject has contacted the ground until the minimum Total Body Center of Mass

APPENDIX B: REVIEW OF LITERATURE

One of the most important domains of athletic training, requiring constant attention from clinicians, is injury prevention. Anterior cruciate injuries (ACL) continue to receive increased attention from a preventative perspective as the injury rates for women continue to be elevated in comparison to ACL injury rates for men. Despite the elevated focus, there is still not a clear understanding on why women are at higher risk than men. The suggested explanations include both intrinsic and extrinsic factors.

Intrinsic factors are those that are anatomically related.[1] Some of the intrinsic factors that have been investigated for sex-related differences in relation to ACL injuries are joint laxity,[2, 3] ligament size,[4] lower extremity malalignment,[2, 5, 6] hormone influences,[7-9] and intercondylar notch configuration.[4] Investigations on intrinsic factors have reported differences between men and women,[1, 4, 10] but like most physical characteristics, there exists a continuum in which one sex may possess characteristics typically considered in the range of the opposite sex's classification. Additionally, even if one of these intrinsic factors were reported to influence injury risk, the application to the athletic population would be likely limited, because the majority of these factors cannot be readily adjusted. Lastly, based on the current research reports,[4, 10, 11] it is not probable that one specific factor in isolation makes women more at risk for ACL injuries than men. Rather, it is more likely a combination of several factors influence the injury rates.

In contrast to intrinsic factors, which are largely not controllable, extrinsic factors are features that are potentially controllable.[12] These factors include muscular strength,[4, 10, 13] playing surfaces,[14] skill levels, and biomechanical movement patterns.[11, 13, 15-23]

Studying extrinsic factors is more applicable to reducing injury risk because these factors can be more readily altered in the clinical context.

Biomechanics between Sexes

Many biomechanical differences have been reported during the execution of performance tasks between men and women.[13, 15-21] These differences theoretically could place the ACL in positions or situations associated with greater injury risk. Specific differences reported include women using: less knee flexion during landing and cutting,[15-17] greater knee valgus angles,[15, 18-20] decreased hamstring activation and increased quadriceps activation,[15, 21] decreased hip flexion,[17] less lower leg internal rotation,[16] and greater ground reaction forces when landing (Figure 2).[13] Men also have greater peak knee flexor moments than women during landing tasks.[13, 18, 24, 25] In addition to sex-related differences existing during performance tasks, differences in biomechanical arthrokinematics of simple exercise execution have been reported. For example, Hollman et al[11] reported that while knee surface kinematics during open chain knee extension were not significantly different between men and women, during closed chain knee extension men used significantly more rolling of the joint to get into full extension, whereas women glided into full extension.

Single-leg squat

Research examining sex-related differences during single-leg squats has been limited. Zeller et al[23] reported that college-aged women performed single-leg squats with significantly more ankle dorsiflexion, ankle pronation, hip adduction, hip flexion, hip external rotation and valgus knee alignment. Additionally, women also used less trunk lateral flexion. This could represent women being less able to control the movement of the hip and ankle. With increased movements at the joints surrounding the knee, compensation forces would likely be transmitted and stressed to the knee. Valgus angles at the knee open the joint and extenuate the instability, placing the ACL at a more vulnerable position with increased stress.

Single-leg Landing

Most research has been conducted examining sex-related differences in single-leg landing biomechanics. Landing tasks used have ranged from horizontal hopping to vertical drop landings. For horizontal hops where subjects took off and landed on their dominant leg, Lephart et al[16] and Fagenbaum et al[22] both reported biomechanical differences between men and women. These studies reported differing results as Lephart et al[16] reported women using less knee flexion and Fagenbaum et al[22] recorded women using more knee flexion than men. Lephart et al[16] also recorded women using greater hip internal rotation, less shank internal rotation maximum angular displacement, and less time to knee flexion and shank internal rotation maximum angular displacements. Fagenbaum et al[22] reported higher normalized quadriceps muscle activity and lower gastrocnemius activity in women compared to men.

The distances the subjects jumped could influence the contradictory knee flexion angles. Lephart et al[16] used standard distances of 25.4 cm and 50.8 cm, whereas Fagenbaum et al[22] used 45% of the subject's height. Therefore, Lephart et al[16] had subjects typically jump a shorter distance. For all distances, females used significantly different knee angles compared to men. Further research could investigate jumping at short, moderate, and long distances to analyze possible joint angle changes as distance changes. Both studies support females landing in positions that suggest decreased control of the hip and displacement times shorter than men. If females are reaching positions that place the ACL at risk in shorter times, the impulse stress at the knee may be increased.

Double-leg Landing

Because most functional activities involve both lower limbs working simultaneously, double leg landings simulating various athletic maneuvers have also been extensively considered. Salci et al[17] compared men and women performing ‘spike’ landings (vertical distance = 40 cm and 60 cm, horizontal distance =10 cm) and ‘block’ landings (vertical distance = 40 cm and 60 cm, horizontal distance = 15 cm). During the 40cm block task, women used significantly less hip flexion and during the 40 cm spike landing women used significantly less knee flexion than men. Men applied significantly less normalized vertical ground reaction forces than the women for all tasks. Women also used significantly higher flexor and extensor peak torques than the woman volleyball players. Positive correlations between knee flexion angles and normalized extensor peak torque for all tasks and knee flexion angles and normalized flexor peak torque for all tasks except the 40 cm block for men were exhibited, but not women. This study again reports results supporting women landing in a position of increased ACL risk. Less knee and hip flexion place the women in more erect postures with higher ground reaction forces acting on the lower extremity. Less torque and control from the hamstrings and quadriceps reduce the control of tibial shear at the knee and may be a factor in females not landing with more energy absorbing squats.

In contrast to primarily vertical landing maneuvers, Chappell et al[18] had subjects take a 3-step approach, land on both feet, followed by either a forward jump, vertical jump or backward jump. Women displayed greater tibia anterior shear than men for all tasks. Both men and women exhibited significantly greater tibia shear during the landing before they jumped backwards than the other two tasks. For the forward jump, women used an extension moment at the knee, where men used a flexion moment. For the vertical jump, both groups used an extension moment, but women were greater, and for the backward jump, men had significantly greater flexion moment than the women. Women also used significantly more valgus moments in executing these tasks than did the men. Women exhibited greater extensor moments at the knee than men in all tasks. With a three-step approach, the tibia is already moving anteriorly when subjects change direction. The extensor moment continues anterior shear in women, whereas men use flexor moments. Flexor moments bring the men into an energy-absorbing squat, where as again, women continue with more extension rotation. Hamstrings decrease anterior shear of the tibia at knee flexion angles less than sixty degrees.

Subjects performed pure drop landings in Decker et al[13] (vertical height= 60 cm) and Ford et al[19] (vertical height= 31 cm) studies. Decker et al[13] reported women used significantly greater knee extension and ankle plantar-flexion at initial contact compared to the men. All lower extremity joints had greater peak angular velocities in women. Women exhibited peak hip extensor moments significantly greater than peak ankle plantar-flexor moments, but men exhibited peak hip extensor moments greater than both the extensor moment and peak ankle plantar-flexor moment. Similar biomechanical differences reported in collegiate athletes were also reported by Ford et al[19] in high school athletes. Girls used increased knee valgus motion compared to the boys. Girls also displayed bilateral differences, as the dominant leg valgus angles were greater than the non-dominant knee. This bilateral difference was not exhibited in boys. Even with subjects of both collegiate and high school skill levels, both studies support women landing in more erect postures with increased adductor movement at the knee.

Skill level and level of competition being a factor in biomechanical differences between men and women presents as less of an issue as high school boys and girls also exhibit similar biomechanics. If athletes have developed sex-related biomechanical differences by high school, Hewett et al[20] used the same task as Ford et al[19] to measure middle school athletes to investigate possible changes that occur during development and growth associated with puberty. Girls in late or postpubertal stages used significantly more medial knee motion than boys did at that age. There was no difference between the sexes before onset of maturation. Girls in the late or postpubertal stages also displayed greater valgus angles than boys at initial contact and peak values. These girls in the postpubertal stage had valgus angles greater than the prepubertal girls. The girls in the late and postpubertal had significantly greater valgus angles on their dominant leg compared to their non-dominant leg. Throughout the maturation stages, boys had increasing hamstring and quadriceps torques, whereas girls' hamstring and quadriceps torques remained constant. Results would suggest these biomechanical differences begin to develop during maturation, or puberty.

Differences in biomechanical execution place the knee at a position for increased anterior shear of the tibia on the femur. With decreased activation of the hamstrings, the quadriceps continue to increase the anterior pull of the tibia without a stronger counterforce. If there is an unbalanced muscular force on the knee, more demand is placed on the ligaments.[19] Women also land in more erect postures with less knee and hip flexion, also placing the knee at a less stable position. At knee flexion angles less than 30 degrees, the hamstrings are even less effective in decreasing the anterior shear of the tibia.[26] Thus, with women landing with straighter knee angles, the hamstrings are even less able to compensate for anterior shear and heightened activation of the quadriceps

Resistance and Plyometric Training

A major aspect of collegiate athletic training is the incorporation of sport specific resistance and plyometric training. This is an aspect of athletic conditioning that is often neglected at the high school level. This may be because of insufficient funds for equipment, lack of proper understanding and supervision, focus purely on skills, or many other factors. Short-term investigations show that neuromuscular training decreases the incidence of knee injuries in women.[27, 28] Following puberty, boys demonstrate a neuromuscular spurt with increased strength, power and coordination that girls do not demonstrate.[29] Following puberty is also when ACL injury rates between men and women become unbalanced.[29] Dynamic neuromuscular training appears to reduce sex differences in force absorption, joint stabilization, muscle imbalances, and functional biomechanics.[30] As a result of this research, there is a strong trend for female athletes to complete programs designed to 'prevent ACL injuries,' which typically last for six to eight weeks. Woman athletes are taught how to jump and land in positions that protect the knee and have less impact on the lower extremity.[27-29, 31] Jump training programs incorporate stretching, plyometric exercises and weight lifting. Jump training programs emphasize jumping with correct posture, jumping straight up with no excessive side-to side movement, soft landing, and instant recoil preparation for the next jump.[29]

Injury Rates

A reduction in injury rates is reported in the found jump training research (Table 2). Hewett et al[27] reported decreases in woman knee injury rates following a 6-week jump training program. The phases of the jump training program focused on technique, strong base of support, power and agility, and maximum vertical height. Hewett et al[27] found that following a neuromuscular training program for high school athletes, an untrained girl group had an injury rate 3.6 times higher than the trained girl group and 4.8 times the boy control group. The girl group that completed the neuromuscular training had an injury incidence rate only 1.3 times that of the boy control group, which was not significant.

Heidt et al[28] investigated a seven-week pre-season conditioning program similar to Hewett et al,[27] but focused purely on high school girl soccer players. This study reported the trained group sustained significantly fewer lower extremity injuries (14%) than the untrained group (33.7%). The majority of the injuries occurred at the knee. Only 42.9% of the injuries of the untrained group occurred during a game, in contrast to the 71.4% of the injuries of the training group. Both these studies reported, not only decreases in injury rate in the trained group compared to untrained girls, but also injury rates similar between these trained groups and boy control groups. The greater amount of injuries in the trained group during games could suggest that they had improved dynamic stability of the knee at less intensity, but were trained as much at full intensity to make these adaptations.

Biomechanical Changes

With reported decreases in injury rate with jump training programs, investigations are comparing where the training programs are affecting the lower extremity and if the ACL risk positions are decreased. Plyometric training has also been suggested to change the biomechanics which athletes execute athletic tasks (Table 4). Hewett et al[24] reported decrease peak landing forces, decrease adduction and abduction moments of the knee, and increased hamstring muscle peak torque, power and hamstring/quadriceps ratio following a six-week jump training program for high school females.[24] Even after the six-week training program, the boy control group still had an extensor moment three times that of the girls. In a similar preseason training program for elite women, Holm et al[31] tested for changes in proprioception, balance, strength and lower limb function. The only change was an increase in dynamic balance. Following the training program, With less adduction and abduction moments at the knee, there is more stability at the knee as the articulating surfaces stay in more contact and allow the collateral and associated muscles to control movement at the knee more efficiently.

These programs could be beneficial for woman athletes, but it unrealistic to feel that every woman athlete is going to attend one of these programs or even be able to afford it. All the current research that was found has been done with high school girl athletes. The purpose of our study is to determine if there are biomechanical changes that occur throughout the first year of collegiate athletic participation.

One of the major additions to collegiate athletic training that a large percentage of high school athletes are not accustomed to is a structured, sport specific resistance and plyometric training program. If biomechanical changes do occur during this first year of collegiate participation, it is of interest if these changes place the lower extremity in a more ACL ‘safe’ or ‘risk’ position. If they are safer positions for the ACL, it supports that woman athletes should be highly encouraged to have structured resistance and plyometric programs in high school. Anterior cruciate ligament injuries could be at elevated rates because woman athletes are not accustomed to these changing biomechanics and have not adapted their dynamic control of the lower extremity. This would again support encouraging female athletes to begin resistance training in high school where the level of competition is not as fast and high.

Biomechanics Testing

For this investigation, participants were tested on double-leg jump with single-leg landing.[16, 22] This test simulated elements of athletic tasks, such as a volleyball spike and block, basketball rebound, lay-up and block, and soccer heading and jumping. This tests allowed us to compare the results of this study with results of the jumping program research, specifically those by Ford et al[19] and Hewett et al.[20, 24] Participants were also tested on the single-leg squat. These tests are commonly used for assessment of hip strength and trunk control.[23] This allowed for analysis of both single-leg and double-leg tasks, which is accurate in comparing the variety of tasks required in athletics. The dominant leg only was tested to help reduce the amount of tasks done and because it has been suggested that subjects will be less likely to fall using the stronger leg, especially when they are fatigued.[22] Current technology prevents researchers from getting accurate testing during actual athletic participation, so testing was done in a controlled biomechanics laboratory.

Peak and angular distance angles at the trunk, hip and knee for the single-leg squat were the dependent variables. Specifically, the peak joint angles include: flexion at the trunk, hip and knee, hip adduction and medial rotation, and knee adduction and lateral rotation. Angular distance angles include abduction/adduction at the trunk, hip and knee, and rotation at the trunk, hip, and knee. Joint moments at the hip, knee and ankle will be the dependent variables for the jumping and hopping tasks. Specifically, the net external joint moments are the extension moments at the hip, knee and ankle, hip adduction and medial rotation, and knee abduction and lateral rotation.

Collected data allowed investigators to analyze differences and compensations in angles between the lower extremity joints and the moments that were created. This study allowed for analysis between sex and three groups (freshman women, sophomore women, freshman men) and between the three joints (hip, knee, ankle). Sophomore men were excluded from the subgroup analysis because of their small group size. This comparison was to determine if sophomores, who have already completed a year of collegiate athletics, have biomechanics similar to the freshmen or if they have already made changes to their athletic execution. Seniors and junior athletes were not chosen due to the tendency of decreased athletic participation and a larger range of ages between freshmen and upper classmen.

Subjects

A deliberate sampling of collegiate athletes and a Division-I university was chosen because 70% of all ACL injuries are athletic related.[24] Participants of the study will include man and woman soccer and female basketball players. Soccer,[8, 12, 13, 16, 18, 32] basketball,[8, 12, 13, 16, 18, 33] and volleyball[13, 17, 18] are three sports most commonly reporting ACL injuries. These sports also report a non-contact mechanism of injury as the most common. This study will not be including volleyball because the Division-I university where the testing will be done does not have men’s volleyball, so there would not be a comparison between the men and women.

References for Review of Literature

1. Orchard J, Seward H, McGivern J, Hood S. Intrinsic and extrinsic risk factors for anterior cruciate ligament injury in australian footballers. *Amer J Sports Med.* 2001;29(2):196-200.

2. Loudon JK, Jenkinds W, Loudon KL. The relationship between static posture and ACL injury in female athletes. *J Orthop Sports Phys Ther.* 1996;24:91-97.

3. Woodford-Rodgers B, Cyphert L, Denegar CR. Risk factors for anterior cruciate ligament injury in high school and college athletes. *J Athl Train.* 1994;29:343-346.

4. Anderson AF, Dome DC, Gautam S, Awh MH, Rennirt GW. Correlation of anthropometric measurements, strength, anterior cruciate ligament size, and intercondylar notch characteristics to sex differences in anterior cruciate ligament tear rates. *Amer J Sports Med.* 2001;29(1):58-65.

5. Beckett ME, Massie Dl, Bowers KD, Stoll DA. Incidence of hyperpronation in the ACL injured knee: a clinical perspective. *J Ath Train.* 1992;27:58-62.

6. Huegel M, Meister K, Rolle G, Indelicato PA, Hartzel J. The influence of lower extremity alignment in the female population on the incidence of noncontact ACL tears. Paper presented at: 23rd Annual Meeting of the American Orthopaedic Society for Sports Medicine, 1997; Sun Valley, ID.

7. Belanger MJ, Moore DC, Crisco JJ, Fadale PD. Knee laxity does not vary with the menstrual cycle, before or after exercise. *Amer J Sports Med.* 2004;32(5):1150-1157.

8. Heitz NA, Eisenman PA, Beck CL, Walker JA. Hormonal changes throughout the menstrual cycle and increased anterior cruciate ligament laxity in females. *J Ath Train.* 1999;34(2):144-149.

9. Wojtys EM, Huston LJ, Lindenfeld TN, Hewett TE, V.H. Greenfield ML. Association between the menstrual cycle and anterior cruciate ligament injuries in female athletes. *Amer J Sports Med.* 1998;26(5):614-620.

10. Wojtys EM, Ashton-Miller JA, Huston LJ. A gender-related difference in the contribution of the knee musculartΩure to sagittal-plane shear stiffness in subjects with similar knee laxity. *J Bone Joint Surg.* 2002;84(1):10-16.

11. Hollman JH DR, Van Dillen LR, Matava MJ. Gender differences in surface rolling and gliding kinematcis of the knee. *Clin Orthop Rel Res.* 2003;413:208-221.

12. Ireland ML. Anterior cruciate ligament injury in female athletes: epidemiology. *J Ath Train.* 1999;34(2):150-154.

13. Decker MJ, Torry MR, Wyland DJ, Sterett WI, Steadman JR. Gender differences in lower extremity kinematics, kinetics and energy absorption during landing. *Clin Biomech.* 2003;18:662-669.

14. Orchard J. Is there a relationship between ground and climatic conditions and injuries in football? *Sports Med.* 2002;32(7):419-432.

15. Malinzak RA, Colby SM, Kirkendall DT, Yu B, Garrett WE. A comparison of knee joint motion patterns between men and women in slected athletic tasks. *Clin Biomech.* 2001;16:438-445.

16. Lephart SM, Ferris CM, Riemann BL, Myers JB, Fu FH. Gender differences in strength and lower extremity kinematics during landing. *Clin Orthop Rel Res.* 2002;401:162-169.

17. Salci Y, Kentel BB, Heycan C, Akin S, Korkusuz F. Comparison of landing maneuvers between male and female college volleyball players. *Clin Biomech.* 2004;19:622-628.

18. Chappell JD, Yu B, Kirkendall DT, Garrett WE. A comparison of knee kinetics between male and female recreational athletes in stop-jump tasks. *Amer J Sports Med.* 2002;30(2):261-267.

19. Ford KR MG, Hewett TE. Valgus knee motion during landing in high school female and male basketball players. *Med Sci Sports Exerc.* 2003;35(10):1745-1750.

20. Hewett TE, Myer GD, Ford KR. Decrease in neuromuscular control about the knee with maturation in female athletes. *J Bone Joint Surg.* 2004;86(8):1601-1608.

21. Colby S, Francisco A, Yu B, Kirkendatt D, Finch M, Garrett Jr. W. Electromyographic and kinematic analysis of cutting maneuvers. *Amer J Sports Med.* 2000;28(2):234-245.

22. Fagenbaum R, Darling WG. Jump landing strategies in male and female college athletes and the implications of such strategies for anterior cruciate ligament injury. *Amer J Sports Med.* 2003;31(2):233-240.

23. Zeller BL, McCrory JL, Kibler WB, Uhl TL. Differences in kinematics and electromyographic activity between men and women during the single-legged squat. *Amer J Sports Med.* 2003;31(3):449-456.

24. Hewett TE, Stroupe AL, Nance TA, Noyes FR. Plyometric training in female athletes. *Amer J Sports Med.* 1996;24(6):765-773.

25. James CR, Sizer PS, Starch DW, Lockhart TE, Slauterbeck J. Gender differences among sagittal plane knee kinematic and ground reaction force characteristics during a rapid sprint and cut maneuver. *Res Quart Exerc Sport.* 2004;75(1):31-39.

26. Bonci CM. Assessment and evaluation of predisposing factors to anterior cruciate ligament injury. *J Ath Train.* 1999;34(2):155-164.

27. Hewett TE, Lindenfeld TN, Riccobene JV, Noyes FR. The effect of neuromuscular training on the incidence of knee injury in female athletes. *Amer J Sports Med.* 1999;27(6):699-713.

28. Heidt RS, Sweeterman LM, Carlonas RL, Traub JA, Tekulve FX. Avoidance of soccer injuries with preseason conditioning. *Amer J Sports Med.* 2000;28(5):659-662.

29. Myer GS, Ford KR, Hewett TE. Rationale and clinical techniques for anterior cruciate ligament injury prevention among female athletes. *J Ath Train.* 2004;39(4):352-364.

30. Rooks DS, Micheli LJ. Musculoskeletal assessment and training: the young athlete. *Clin Sports Med.* 1988;7:641-677.

31. Holm I, Fosdahl MA, Friis A, Risberg MA, Myklebust G, Steen H. Effect of neuromuscular training on proprioception, balance, muscle strength, and lower limb function in female team handball players. *Clin J Sport Med.* 2004;14(2):88-94.

32. Bjordal JM, Arnoy F, Hannestad B, Strand T. Epidemiology of anterior cruciate ligament injuries in soccer. *Amer J Sports Med.* 1997;25(3):341-346.

33. Gomez E, DeLee JC, Farney WC. Incidence of injury in Texas girls' high school basketball. *Amer J Sports Med.* 1996;24(5):684-688.

APPENDIX C: PREVIOUS RESEARCH

Table C1. Findings from biomechanical studies

Researchers	Subjects & Dependant Variables	Testing Tasks	Significant Results
Salci Y, Kentel BB, Heycan C, Akin S, Korkusuz F.[17] Comparison of landing maneuvers between male and female college volleyball players. *Clin Biomech*. 2004; 19:622-628.	8 men & 8 women National Volleyball players Kinematic, Kinetic & Isokinetics	Spike Landing: Land from 40cm & 60cm platform from 10cm away Block Landing: Land from both heights from 15 cm away	40 cm Spike: women sig. less knee flexion 40 cm Block: women sig. less hip flexion
Ford KR, Myer GD, Hewett TE.[19] Valgus knee motion during landing in high school female and male basketball players. *Med. Sci. Sports Exerc*. 2003; 35:1745-1750.	34 boy & 47 girl HS basketball players Kinematics	Drop from 31cm box onto force plates and immediately do max vert. jump	Girls sig. less knee flexion at contact, greater GRF at max knee flexion
Chappell JD, Yu B, Kirkendall DT, Garrett WE.[18] A comparison of knee kinetics between male and female recreational athletes in stop-jump tasks. *Amer J Sports Med*. 2002; 30:261-267.	10 man & 10 woman recreational athletes Kinetics	Approach followed by double-leg forward hop; vertical jump or backward jump	All tasks: women sig. more tibia shear, sig. more knee ext. moment, more valgus moments during landing
Decker MJ, Torry MR, Wyland DJ, Sterett WI, Steadman JR.[13] Gender differences in lower extremity kinematics, kinetics and energy absorption during landing. *Clin Biomech*. 2003; 18:662-669.	12 man & 9 woman recreational athletes Kinematics, kinetics & energy absorption	Double-leg landing from 60cm box	Women sig. greater knee ext., ankle plantar-flexion angles at contact; sig. greater peak hip ext. moment than peak ankle plantar-flexor moment for women, while men had greater peak hip ext moment than both knee ext & ankle plantar-flexor moments
Fagenbaum R, Darling WG.[22] Jump landing strategies in male and female college athletes and the implications of such strategies for anterior cruciate ligament injury. *Am J Sports Med*. 2003; 233-241.	6 man & 8 woman collegiate basketball players Electromagnetics, Kinematics	Max vertical jump with 25cm forward jump-single-leg land; single-leg land from 25.4cm; single-leg land from 50.8cm	All tasks: women sig. more knee flexion before & after landing, greater knee flexion accelerations, greater quadriceps EMG activity & lower gastrocnemius activity
Lephart SM, Ferris CM, Riemann BL, Myers JB, Fu FH.[16] Gender differences in strength and lower extremity kinematics during landing. *Clin Ortho Rel Res*. 2002; 401:162-169.	15 D-I woman athletes & 15 matched recreational men Kinematics & Isokinetics	Single leg landing from 20cm platform Single-leg forward hop	Both tasks: women sig. less knee flexion, lower leg internal rotation after impact, less time to reach maximum knee flexion Relative weakness of women quadriceps & hamstrings

James CR, Sizer PS, Starch DW, Lockhart, TE, Slauterbeck J.[25] Gender differences among sagittal place knee kinematic and ground reaction force characteristics during a rapid spring and cut maneuver. *Res Quart Exerc Sport*. 2004; 75:31-39.	19 boy & 19 girl HS & collegiate basketball players Kinematic & GRF	Rapid sprint with 60 degree angle cut	Girls signf. Greater knee valgus angles, female dominant leg signif. greater valgus angles than non-dominant leg
Zeller BL, McCrory JL, Kibler WB, Uhl TL.[23] Differences in kinematics and electromyographic activity between men and women during the single-legged squat	9 man & 9 woman collegiate athletes Kinematics and EMG	Single-leg squats on dominant leg	Women signif. greater dorsiflexion, ankle pronation, hip adduction, hip flexion, hip external rotation, knee valgus alignment, less trunk lateral flexion

Table C2. Effects of neuromuscular training on injury rates

Researchers	Subjects	Intervention	Significant Results
Hewett TE, Lindenfeld, TN, Riccobene, Noyes FR.[27] The effect of neuromuscular training on the incidence of knee injury in female athletes. *Amer J Sports Med*. 1999; 27:699-713.	Training group: 248 HS girl athletes Untrained group: 463 HS girl athletes Male control: 434 HS boy athletes	6 week jump training program: 60-90 minutes, 3 times/week. Technique, Fundamental, Performance phases	Training group had fewer serious knee injuries than untrained group. Untrained group had greater serious knee injuries than boy control group, but no difference b/t trained and boy control groups
Heidt, RS, Sweeterman LM, Carlonas RL, Traub JA,Tekulve Fx.[28] Avoidance of soccer injuries with preseason conditioning. *Amer J Sports Med*. 2000; 28:659-662.	Training group: 42 HS girl soccer athletes Untrained group: 258 HS girl soccer athletes	7 week preseason program of specific cardiovascular conditioning, plyometrics, sport cord drills, strength training, flexibility	Training group had fewer lower extremity injuries than untrained group.

Table C3. Effects of neuromuscular training on biomechanics

Researchers	Subjects	Intervention	Significant Results
Hewett TE, Stroupe AL, Nance TA, Noyes FR.[24] Plyometric training in female athletes. *Amer J Sports Med*. 1996; 24:765-773.	Training group: 11 HS girl volleyball players Control group: 9 HS boy	6 week jump-training program: 2 hrs, 3 days/week. Technique, Fundamental, Performance phases & weight training	Trained girls had less peak landing force than pre-training, adduction/abduction moment decreased, boys had extensor moment 3x that of girls b/f & after training, girls had increased hamstring strength, power & hamstring/quad ratio after training
Holm I, Fosdahl MA, Friis A, Risberg MA, Myklebust G, Steen H.[31] Effect of neuromuscular training on proprioception, balance, muscle strength, and lower limb function in female team handball players. *Clin J Sport Med*. 2004; 14:88-94.	Training group: 27 woman elite handball players	5-7 week progression program then 1x/week during the season: 15 min Floor, wobble board, & balance mat exercises	Following training, improvement in dynamic balance.

APPENDIX D: TESTING DOCUMENTATION

Testing Form

Subject #____________ Date:______________ Age:______________

Height:_____cm(*2.54)______inches Weight:______kg(*2.2)_____lbs

Dominant Leg:_____________ Shoe Size:_______________

Testing 1:

DBPJ Toe reach______________Max jump__________________

Difference:______________75%__________+ toe reach_____________

SLL: Toe reach______________Max jump__________________

Difference______________75%__________+toe reach______________

SLH: trial 1____________ trial 2____________ trial 3___________ Aver.__________

Consent Form

Email______________________________

Name:_________________________ Phone_____________________________

JIANN-PING HSU SCHOOL OF PUBLIC HEALTH
POST OFFICE BOX 8076
STATESBORO, GEORGIA 30460-8076
TELEPHONE: (912) 681-0200
FAX (912) 681-0381
E-Mail Address PH-office@georgiasouthern.edu

CONSENT TO ACT AS A SUBJECT IN AN EXPERIMENTAL STUDY

Title: Biomechanical changes in collegiate freshman and sophomore athletes associated with one season of athletic participation

1. Primary Investigators:

Caren M. Walls, ATC
Graduate Student, Athletic Training
Georgia Southern University
(O): (912)681-5686 (C): 912-481-1503

Bryan L. Riemann, PhD, ATC
Assistant Professor, Sports Medicine
Georgia Southern University
(912)681-5268

Graduate Research Assistant
Ali Bauer, ATC
Graduate Student, Athletic Training
Georgia Southern University

2. Purpose:

We are attempting to study biomechanical changes in freshman and sophomore athletes. We will be investigating changes between males and females during one season of athletic participation. The results of this study will help us to further understand the effects of resistance training and conditioning on the biomechanics of simple motor tasks.

3. Procedures:

You are being asked to participate in this study because you have no history of neurological, vestibular or balance disorders. Additionally you have no history of lower extremity surgery or major injury in the past 12 months. Sixty participants will be asked to participate in this investigation. If at any time during the study you sustain an injury that prevents you from being able to successfully and safely perform all the tasks when scheduled to be tested, you will be excused from the study.

If you agree to participate in this study you will be scheduled for a private testing session. At the beginning of the session, you will be given a full description and demonstration of each task, followed by sufficient supervised practice time to become completely familiar with each of the tasks. Following overview of the study and practice with the tasks we will place special sensors on the skin of your feet, lower legs, thighs, back and trunk. These sensors provide data about the position of each body segment. You will be asked to perform the following tasks:

<u>Single-leg Squat</u>. You will be asked to stand on your dominant leg (defined by the leg which you would chose to kick a soccer ball with) with your hands on your hips, and back straight. You will be asked to squat down as far as you can without loosing your balance and return to your starting position. Three trials of five continuous squats, at a rate of 1 squat/2 seconds will be completed

<u>Double-leg jump with double-leg landing</u>. You will be asked to perform a maximum vertical jump. 75% of your maximum vertical jump will be used as your target height for the trials. You will be asked to stand with one foot on each force plate, jump to touch your target height, and land with one foot on each force plate. You are free to squat down before and after your jump if this is more comfortable for you. Five individual jump trials will be completed.

<u>Double-leg jump with single-leg landing</u>. Your 75% of your maximum vertical jump again be used for this task. You will stand with one foot on each force plate, jump to your target height, and land on your dominant foot only. You are free to squat down before and after your jump if this is more comfortable for you. Five individual jump trials will be completed.

<u>Single-Leg Hop</u>. You will be asked to stand on your dominant leg and hop forward as far as you can onto the forceplate. You will perform 3 practice trials to determine an average to use at the target distance. You will land only on your dominant leg and 3 trials will be completed.

4. Discomforts and Risks

The risk assumed during the testing is mild. All of the tasks in the study are similar to normal activities of athletic conditioning. To minimize any risk of injury, you will be instructed on the proper test procedures and will be spotted during all of the tasks. Only trained laboratory personnel will conduct the testing and procedures.

5. Benefits

There are no direct benefits to you for participating in this study. Society will likely benefit from your participation as we further the effects of resistance training and conditioning on biomechanics.

6. Duration:

Each test session will require less than one hour. Freshman females will be tested three times during the year. All other groups will be tested once.

7. Statement of Confidentiality:

You understand that any information about you or your records will be handled in a confidential (private) manner consistent with medical records. Your identity on all records will be indicated by a case number. You will not be specifically mentioned in any publication of research results. However, in unusual cases my research records may be inspected by appropriate government agencies or released to an order from a court of law. All information and research records will be kept for a period of five years after the termination of this investigation.

8. Questions:

Any questions you have pertaining to the research have been, and will continue to be answered by the investigators listed at the beginning of this consent form at the phone numbers given (912-681-5686). Any questions you have concerning your rights as a subject will be answered by the Georgia Southern University IRB Office (912-681-5465).

9. Cost and Payments:

There are no costs or payments associated with participation in this study.

.

10. Compensation for Injury:

Georgia Southern University investigators and their associates recognize the importance of your voluntary participation to their research studies. These individuals and their staffs will make reasonable efforts to minimize, control and provide any necessary first aid needed for any injuries that may arise as a result of this research.

You understand that medical care is available in the event of injury resulting from research but that neither financial compensation nor free medical treatment is provided. You also understand that you are not waiving any rights that you may have against the University for injuries resulting from negligence of the University or investigators. If you believe that you are injured as the result of the research procedures being performed, please contact immediately the Principal Investigator listed on the cover sheet of this form or the Georgia Southern University Institutional Review Board IRB Coordinator at the Office of Research Services and Sponsored Programs at (912) 681-5465.

11. Voluntary Participation:

You understand that you are not required to take part in this research study and, if you change your mind you can withdraw at any time. You also understand that you may be removed from the research study by the investigators in the event of an inability to complete the testing procedures.

12. Penalty:

Your decision whether or not to participate in this study or to withdraw from participation will have no affect on your status with the Georgia Southern University or any other benefit to which you are entitled.

You must be 18 years of age or older to consent to participate in this research study. If you consent to participate in this research study and to the terms above, please sign your name and indicate the date.

You will be given a copy of this consent form for your records.

Title: Biomechanical changes in collegiate freshman and sophomore athletes associated with one season of athletic participation

Principle Investigator: Caren Walls, ATC, 1205 Hanner, 681-5686, cwalls1@georgiasouthern.edu
Cell: 912-481-1503
Other Investigator: Ali Bauer, ATC, 681-5686, abauer1@georgiasouthern.edu
Faculty Advisor: Bryan Riemann, PhD., ATC, PO box 8082 Statesboro, GA 30458
briemann@georgiasouthern.edu

______________________________ ______________
Subject’s signature Date

I, the undersigned, verify that the above informed consent procedure has been followed.

___________________________ _________________
Investigator’s Signature Date

Medical History

Biomechanics Laboratory of Georgia Southern University
MEDICAL HISTORY FOR RESEARCH

Today's Date: _____/_____/_____

Name: Email: Phone:

Personal Information

Age:_____ Date of Birth: _____/_____/_____ Sex:______

Dominant Leg: L R Shoe size:_____________

Personal Medical History

Do you have any known allergies? ______ YES ______NO If YES, please explain:____

____

Please check the following disease conditions that you **had** or currently **have**:

____ High blood pressure	____ Aneurysm	____ Abnormal chest X-ray
____ High blood cholesterol	____ Anemia	____ Asthma
____ High blood triglycerides	____ Diabetes	____ Emphysema
____ Angina pectoris	____ Jaundice	____ Bronchitis
____ Heart attack	____ Hepatitis	____ Thyroid problems
____ Heart surgery (catheter, bypass)	____ Infectious mononucleosis	____ Hernia
____ Heart failure	____ Phlebitis	____ Cancer
____ Heart murmur	____ Gout	____ Epilepsy or seizures
____ Stroke/transient ischemia attacks	____ Kidney stones	____ Prostate problem
____ Rheumatic fever	____ Urinary tract infections	____ Osteoporosis
____ Arteriosclerosis	____ Emotional disorder (depression, etc.)	____ Eating disorder

Please provide dates and explanation to any of the above which you checked:

____

____

Have you experienced, or do you currently experience any of the following on a *recurring* basis?

	At rest: YES	NO	During exertion: YES	NO
Shortness of breath	____	____	____	____
Dizziness, lightheadedness, fainting	____	____	____	____
Daily coughing	____	____	____	____
Discomfort in the chest, jaw, neck or arms (pressure, pain, heaviness, burning, numbness)	____	____	____	____
Skipped heart beats or palpitations	____	____	____	____
Rapid heart rate	____	____	____	____
Joint soreness	____	____	____	____
Joint swelling	____	____	____	____
Slurring or loss of speech	____	____	____	____
Unusually nervous or anxious	____	____	____	____
Sudden numbness or tingling	____	____	____	____
Loss of feeling in an extremity	____	____	____	____
Blurring of vision	____	____	____	____

If YES to any of the above, please explain:

____

____

____

Orthopedic/Musculoskeletal Injuries

Please check the following disease or conditions which you had or currently have:

____ Stiff or painful muscles
____ Swollen joints
____ Painful feet
____ Severe muscle strain
____ Limited range of motion in any joint
____ Bursitis
____ Muscle weakness
____ Amputation
____ Fractures or dislocations
____ Tennis elbow
____ Torn ligaments
___ Pinched nerve
____ "Trick" knee/knee injury
____ Head injury
____ Shoulder injury
____ Ankle injury
____ Whiplash or neck injury
____ Slipped disc
____ curvature of spine

Do any of the above limit your ability to exercise? _____ YES _____NO If YES to any of the above, please explain

____

____

Resistance Training History

Please check any of the following which you have regularly (3 or more times a week) used for training in the past *3 months*

Activity	Frequency (days/week)	Time (min/session)	How long (years)
Free Weights	______________________	______________________	______________________
Olympic Lifts	______________________	______________________	______________________
Resistance Bands	______________________	______________________	______________________
Plyometrics	______________________	______________________	______________________
Medicine Balls	______________________	______________________	______________________
Resistance Machines	______________________	______________________	______________________
Body Weight	______________________	______________________	______________________
Other	______________________	______________________	______________________

(Please explain)____

Please check any of the following which you have regularly (3 or more times a week) used for training in the *past year*

Activity	Frequency (days/week)	Time (min/session)	How long (years)
Free Weights	______________________	______________________	______________________
Olympic Lifts	______________________	______________________	______________________
Resistance Bands	______________________	______________________	______________________
Plyometrics	______________________	______________________	______________________
Medicine Balls	______________________	______________________	______________________
Resistance Machines	______________________	______________________	______________________
Body Weight	______________________	______________________	______________________
Other	______________________	______________________	______________________

(Please explain)____