The Pennsylvania State University

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CORE PERFORMANCE MEASURES AND BODY SEGMENT KINEMATICS FOLLOWING KNEE JOINT LOADING AMONG FEMALE COLLEGIATE ATHLETES

A Thesis in

Kinesiology

by

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ABSTRACT

Women participating in sports are three-times more likely to suffer anterior cruciate ligament (ACL) injury than men. Consequently, incidence of injury varies among different sports in which women engage; specifically, women's ice hockey players display a markedly lower rate compared with lacrosse, and field hockey. While the inherent dynamics of individual sports influence incidence, modifiable factors may also contribute to these disparate ACL injury rates, and represent variables that clinicians could address to reduce risk. Core strength, and endurance are such variables proposed to be related to ACL injury risk, and intervention programs targeted at improving these measures are suggested to curb incidence. During dynamic movement tasks in sports, such as landing, lesser measures of core performance may cause the center of mass to shift in a manner that heightens knee valgus angle, which may load the ACL, and result in injury. Landing represents a common non-contact mechanism of ACL injury, and biomechanical approach to studying body segment responses to knee joint loading; thus, the aim of this study was to compare core performance, and kinematic landing profiles among Division-I collegiate female student-athletes participating in ice hockey, lacrosse, and field hockey. We hypothesized that ice hockey players would demonstrate greater core performance measures as well as lesser lateral trunk lean, and knee valgus angles upon landing compared with lacrosse, and field hockey. The outcomes of this study demonstrate that ice hockey players demonstrate greater core performance measures, which may influence body segment kinematics associated with knee loading mechanisms that result in ACL injury. Practitioners that operate in competitive athletics may use these data to identify modifiable factors, like core performance, in an effort to potentially improve body segment responses to destabilizing loads imparted to the knee joint for diminishing ACL injury risk in collegiate women's sports.

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Chapter 1

INTRODUCTION

Approximately 250,000 anterior cruciate ligament (ACL) tears occur each year in the United States[1,2] amounting for over $2 billion in annual surgical costs.[3] This economic burden is exacerbated given that eighty percent of those who sustain an ACL tear develop knee complications such as osteoarthritis or meniscal tears 5-15 years post-injury.[4] Anterior cruciate ligament tears frequently occur with non-contact mechanisms that load the knee.[3,5,6] During these events, the most stress is placed on the ACL when there is excessive knee valgus.[7,8] Females intrinsically have a greater knee valgus angle which is a factor that may contribute to an ACL-tear risk that is three times higher than males[9]; however, a myriad of other extrinsic factors may underpin ACL injury incidence in females, particularly with those engaged in physical activity. Consequently, there is a disparity in ACL-tear incidence among women's ice hockey, lacrosse, and field hockey, which have associated injury rates of 0.02, 0.23, and 0.11 per 1000 athletic exposures, respectively[10]; yet, a dearth of information exists to elucidate the modifiable factors that contribute to these variable injury rates among female collegiate sports.

It has been postulated that decreased core stability is a risk factor for suffering an ACL tear[11,12] where reduced joint stability is secondary to muscular fatigue.[13] The core is defined as the ensemble of active structures in the torso and pelvis that contribute to lumbopelvic and trunk stability and acts as a base to which the extremities attach for dynamic movements.[14–16] Evidence demonstrates that fatigued muscles have a hindered capacity to stabilize joints when exposed to loading.[17] A similar phenomenon has been associated between fatigued core musculature and altered joint kinematics that heighten lower extremity injury risk. Consequently, subsequent to core fatigue, cyclists demonstrate increased frontal plane knee motion during pedaling, suggesting aberrant lower extremity kinematics that could increase susceptibility to joint injury.[18]

A common knee joint loading mechanism associated with ACL injury in physical activity is landing from a jump.[19,20] In the analysis of landing characteristics among female athletes, those who exhibit greater lateral trunk lean (LTL) and knee valgus (KV) angles are associated with a higher incidence of ACL injury.[21] Furthermore, lesser measures of core endurance result in poor postural control, which may impair the capacity to stabilize a joint following a destabilizing load like landing.[22] Subsequently, core stability training is associated with improved landing kinetics, and reduced implications for lower extremity injury in female athletes[23]; however, there is a scarcity of information detailing the effect of core fatigue on body segment kinematics during landing. Therefore, the purpose of this experiment was to profile core performance measures, and body segment kinematics upon knee joint loading among female collegiate athletes with disparate rates of ACL injury.

Greater measures of core performance have been associated with improved postural stability[24]; thus, we hypothesized that due to the nature of the repetitive single-leg stance on a narrow base of support on a low-friction surface, women's ice hockey players may inherently have greater postural stability, and hence core performance compared with lacrosse, and field hockey players. As the result of having greater indices of core strength, and endurance, ice hockey players would also demonstrate comparatively better body segment kinematics upon joint loading that reflect lesser LTL, and KV angles.

Chapter 2

METHODS AND MATERIALS

Experimental Design and Participants

A descriptive laboratory study experimental design was used to explore differences among groups for core performance measures, and body segment kinematics upon knee joint loading. Data to determine such outcomes were collected during one testing session. Convenience sampling was used for enrollment. Sample size calculation was based on the results of Herrington[25] for average knee valgus angle from a unilateral vertical drop landing. Using a maximum difference of 16°, standard deviation of 6.1°, and significance level of 0.05, a minimum of 4 participants per group was necessary to achieve or surpass an 80% power threshold for a projected one-way analysis of variance (ANOVA).

Following Institutional Review Board approval, 26 National Collegiate Athletic Association Division I female student-athletes from The Pennsylvania State University Women's Ice Hockey, Lacrosse, and Field Hockey programs were recruited to voluntarily participate in this study. Written informed consent was obtained from all participants before data collection. Participants with a history of major knee injury, such as fracture or complete rupture of a ligament or tendon, surgery on the non-dominant leg, a lower extremity injury or pregnancy at the time of the study, and smokers were excluded from the study. Prior to testing, we measured participant height, body mass, as well as floor-to-greater-trochanter length, and determined leg dominance by asking participants which leg they would use to kick a ball for the furthest distance, and with the most accuracy.[26] A summary of participant demographics, and anthropometrics are provided in Table 1.

Table 1. Participant Demographics, and Anthropometrics by Sport

Sport	n	Mean ± SD				Median			
		Age	Height (cm)	Body Mass (kg)	RPI (cm · $kg^{-1/3}$)	Age	Height (cm)	Body Mass (kg)	RPI (cm · $kg^{-1/3}$)
IH	10	19.3 ± 1.6	168.4 ± 4.9	68.5 ± 4.9	41.2 ± 0.8	18.5	166.5	68.7	41.0
LAX	12	19.8 ± 1.1	167.5 ± 5.4	66.2 ± 4.9	41.4 ± 1.0	20.0	165.7	66.5	41.5
FH	4	19.5 ± 0.6	168.5 ± 9.7	66.6 ± 8.9	41.3 ± 1.7	19.5	171.0	66.6	41.4

Abbreviations: IH = ice hockey; LAX = lacrosse; FH = field hockey; RPI = reciprocal ponderal index

Furthermore, we placed flat, adhesive markers (Color Coding Labels, Avery Products Corporation, Strongsville, Ohio) at the following body segment sites: 2 cm below the sternal notch; right, and left anterior superior iliac spines (ASIS); knee-joint center of the non-dominant leg; center of the distal tibia at the ankle mortise of the non-dominant leg. Marker placement was consistent with the locations necessary to calculate LTL and KV angle.[27,28] After this preparatory period, participants performed a standardized sequential warm-up, which consisted of 5 minutes of treadmill walking at 1.2 m/s followed by 20 jumping-jacks, and 10 body-weight squats.[26]

Baseline Single-Leg Vertical Drop Landing

Participants performed three trials of a barefoot single-leg vertical drop landing from a 30-cm box onto their non-dominant leg in order to later assess body segment kinematic measures. The non-dominant leg was selected given evidence that female athletes have a greater incidence of ACL injury on this leg[29,30], which is proposed to stem from a decreased joint stabilization capacity associated with reduced neuromuscular control for the non-dominant leg.[31] A 30-cm height was chosen due to its prevalence in related experiments[28,32], and as a means to facilitate comparisons among this, and associated studies. Prior to each trial, participants were instructed to quietly stand on the non-dominant leg with hip, and knee joints in neutral, the metatarsal transverse arch at the front edge of the box, and hands by their sides. The contralateral dominant-leg hip, and knee joints were flexed to approximately 30 degrees so as not be in contact with the non-dominant leg or box (Figure 1).

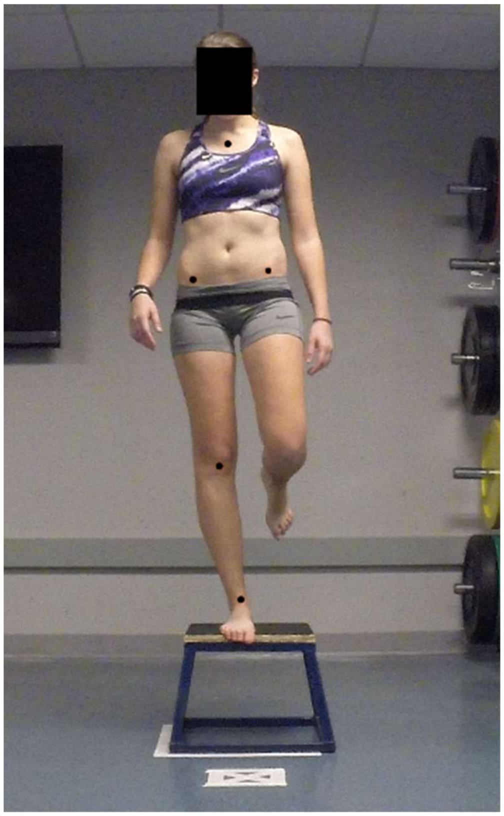

Figure 1. Starting position for the single-leg vertical drop landing

On cue, participants performed a vertical drop landing by hopping off of the box onto a marked target 30 cm[28] in front of the box. Participants were directed to land on their non-dominant leg only, and maintained balance on the leg for 2 s until the experimenter indicated the trial was over. Ten seconds of rest separated each trial. To gain familiarity with the protocol, participants were given three practice trials before data collection. Each data collection trial was recorded via a video camera (Hero 3+ Black Edition, GoPro Inc., San Mateo, California) that was oriented perpendicular to the frontal plane, and placed 3 m away from the landing target at the height of the participant's knee. The camera captured data at a sampling rate of 120 frames-per-second, 720p video resolution, and narrow field of view. Video recordings were used for 2-dimensional kinematic analysis, which has been shown to be valid and reliable[35], as well as comparable to 3-dimensional analysis for frontal plane motions.[33,34]

Baseline Core Performance Assessment

Participants performed core strength assessments for trunk flexion, and extension as measured by a handheld dynamometer (Nicholas Manual Muscle Tester, Lafayette Instrument Company, Lafayette, Indiana) which is a valid and reliable manner in which to assess muscle strength.[36] A glute-ham bench (Mach-II, Sorinex, Lexington, South Carolina) was adjusted so the hip padding was placed at the height of the participant's iliac crests for stabilization during testing. An inelastic belt-strap was placed around the participant's trunk, and secured to the foot-plate support bar of the bench. To test trunk flexion, the participant stood facing away from the bench with the dynamometer fixed to the midpoint of sternum, which was secured by the belt-strap (Figure 2).

Figure 2. Testing position for assessing isometric trunk flexion force

The participant was instructed to flex their trunk by way of a maximal voluntary isometric contraction for a 5-s period in an effort to record peak force (N). Following a demonstration of assessment technique, participants completed one practice trial followed by one minute of rest before completing three data collection trials each separated by 10 s of rest. The peak force for each data collection trial was averaged, and analyzed. A similar method was used to measure trunk extension with modifications that included having the participant face the glute-ham bench with the dynamometer fixed to the seventh thoracic vertebrae that was secured by the belt-strap. These methods are similar to that of Harding et al[37] which have been shown to be valid and reliable. For participant comfort, generic 5-mm high-density foam was placed on the dynamometer pressure plate that served as a cushion between the device and body during testing.

Immediately following strength testing, participants performed a core endurance assessment (CEA) to self-perceived fatigue in a manner similar to that described by Abt et al.[18] For this portion of the experiment, participants wore a weighted vest adjusted to 15% of their body mass while completing a continuous circuit of sit-ups, back extensions, side-crunches, and seated trunk twists performed in a randomized fashion. Descriptions for these exercises are provided in Table 2.

Table 2. Core Endurance Assessment to Self-Perceived Fatigue

Exercise	Start Position	Movement
Sit-ups	Supine in glute-ham bench, arms across chest, trunk flexed to 90°	Extend trunk to neutral, then flex trunk to 90°
Back Extensions	Prone in glute-ham bench, arms across chest, trunk in neutral	Flex trunk to 90°, then extend trunk to neutral
Side-Crunches	Side-lying in glute-ham bench, arms across chest, trunk in neutral	Sidebend trunk to 30°, then sidebend trunk to neutral
Seated Trunk Twists	Seated on floor, knees bent to 90°, feet off ground, trunk rotated to the right	Rotate trunk to the left and touch ground, rotate trunk to the right and touch ground

Every exercise repetition was synchronized to an audible, 36-beats-per-minute metronome cadence in order to standardize the time between, and the time to complete each repetition.[38,39] The metronome beat coincided with the completion of a repetition as they returned to the start position of the respective exercise. Prior to beginning the CEA, the glute-ham bench was adjusted so that the distance from the foot-plate to the center of the hip pad was equal to the floor-to-greater-trochanter height of the participant; furthermore, examiners demonstrated each exercise before participants were given one practice trial for each exercise that consisted of five repetitions with no rest intervals. With a data collection trial, participants were instructed to perform as many repetitions as possible for each exercise in the circuit until reaching self-perceived fatigue, a marker of true, physiological fatigue.[40] Self-perceived fatigue was defined as the participant stopping a particular exercise due to an inability to continue with repetitions because of self-reported exhaustion, an examiner's observation for the participant's inability to return to the start position of an exercise[41,42] for two consecutive metronome beats or breaking cadence with the metronome for four consecutive beats. The duration of each exercise was timed (s) from start to finish, and used as an index of endurance. Each participant completed the entire circuit in a continuous fashion with no rest intervals between exercises or repetitions.

Post-Core Endurance Assessment

Immediately following completion of the CEA, participants performed a second bout of trunk flexion, and extension strength testing to gauge the amount of fatigue that was induced by the protocol. Post-CEA strength testing was done in the exact manner as previously described.

Following the post-CEA core strength assessment, a second cycle of assessing single-leg vertical drop landings was conducted in the same fashion as previously described, allowing for comparisons of the body segment kinematics for before and after the CEA.

Post-Hoc Video Analysis of Single-Leg Vertical Drop Landing

Video recordings of the single-leg vertical drop landing trials were converted to frame-by-frame image sequences in Adobe Premiere Pro (Version 11, Adobe Systems, Inc., San Jose, California) for body segment kinematic data processing. Kinematic analysis consisted of LTL, and KV angles at initial contact, LTL at the time of peak KV, as well as peak LTL, and KV angles upon landing. Image sequences spanned from when the participant's foot made initial contact with the ground to 240 frames afterwards, equating to 2 s in real-time to correspond with the duration the participant maintained the single-leg stance position after landing from the box. Adobe Photoshop (Version 11, Adobe Systems, Inc., San Jose, California) was used to overlay and to find the midpoint of a line connecting the left and right ASIS. ImageJ (National Institutes of Health, Bethesda, Maryland) was used for all angle calculations, which has been shown to be reliable for digital angle measurements.[43]

Lateral trunk lean was calculated by measuring the degree between the global vertical axis and a line drawn from the midpoint of the trans-ASIS line to the marker that was placed 2 cm below the sternal notch per the method described by Clark et al[27] (Figure 3A). Knee valgus angle was calculated from the degree denoted by a line drawn from the ASIS of the landing leg to the knee-joint center, and the knee-joint center to the center of the distal tibia at the ankle mortise.[28,44] A "positive" denotation was assigned to a KV angle in which the reference lines became acute in the lateral direction (valgus); a "negative" denotation was assigned if the reference lines became acute medially (varus). The absolute value of the difference from 180° to which the angle was valgus or varus was taken and the appropriate positive or negative value was assigned (Figure 3B). Averages of the three data collection trials were used for comparative analyses.

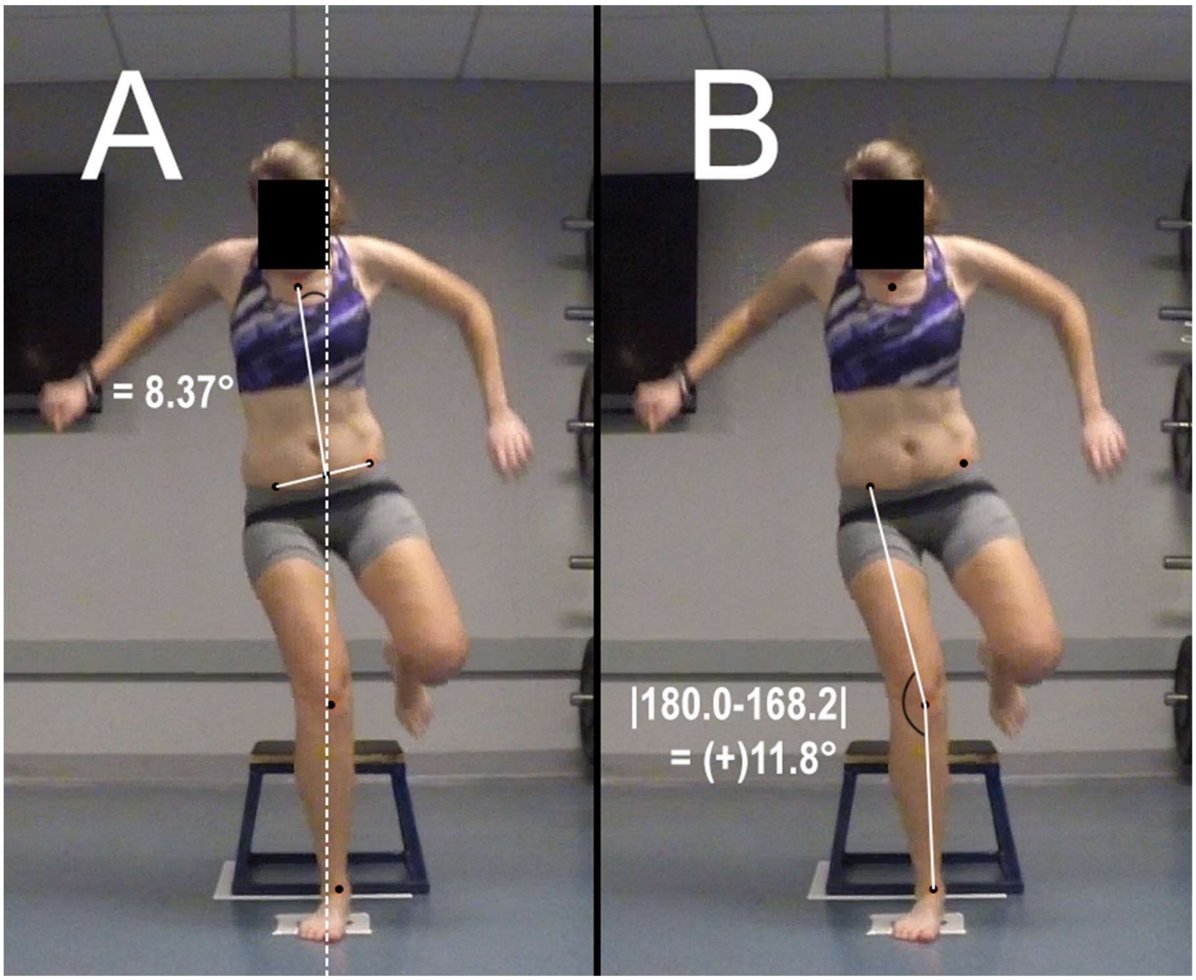

Figure 3. (A) Determination of LTL: the participant's trunk is 8.37° lateral to the global vertical axis (represented by the dashed line). **(B)** Determination of KV: the participant's knee is at a valgus angle of 11.8°, and is denoted as "positive."

Statistical Analyses

The intra-class correlation coefficient assessed reliability of measures. This consisted of using a two-way mixed effects model for consistency among multiple raters/measurements (3, *k*).

A one-way ANOVA was projected to assess differences among groups for single-leg vertical drop landing kinematics, and core performance assessments before, and after the CEA. The specific variables of interest analyzed included: LTL, and KV angles at initial contact as well as peak LTL, and KV angles upon landing; isometric trunk flexion, and extension peak force. Furthermore, total time for each exercise of the CEA was examined. Residual analysis of each variable was completed to examine if the data met necessary assumptions for ANOVA. In the event the data did not meet these assumptions, the Kruskal-Wallis test, a comparable non-parametric statistical analysis, was elected to be applied. An *a priori* value of $P \leq 0.05$ denoted statistical significance among groups. In the event of a noted statistical difference for the ensemble model, subsequent pairwise comparisons analyzed differences between groups; these were projected to be Tukey's Honestly Significant Difference or Mann-Whitney with Bonferroni correction for respective parametric or non-parametric tests. Cohen's effect sizes (*d*) were also calculated to report the standardized magnitude of difference between groups for each variable mean, and were reported as "positive" if the result was in accordance with the *a priori* hypotheses, and "negative" if contrary. Probability plots were assessed to ensure means were normally distributed for Cohen's *d* analysis. Conventional thresholds for interpreting small, medium, and large effect sizes were 0.20, 0.50, and 0.80, respectively.[45] A 95% confidence interval accompanied the effect size to offer a measure of clinical significance.

Chapter 3

RESULTS

All reliability measures were found to be equal to or greater than 0.700. Residual analyses revealed that participant body mass was the only variable that met the assumptions for ANOVA to compare differences among group means; therefore, the non-parametric approach, which focused on comparing differences among group medians, was applied. No statistically significant differences were found for age (P = 0.636), height (P = 0.607), mass (P = 0.621), and reciprocal ponderal index (P = 0.802).

Baseline Body Segment Kinematic Measures

No statistically significant differences existed for baseline kinematic variables (P = 0.683 for LTL angle at initial contact; P = 0.726 for LTL angle at peak KV; P = 0.327 for peak LTL angle; P = 0.478 for KV angle at initial contact; P = 0.668 for peak KV angle). However, ice hockey players displayed a greater LTL angle at initial contact compared with field hockey as evidenced by a large effect size. Additionally, field hockey had a greater peak LTL angle than ice hockey and lacrosse, and greater KV angle at initial contact than ice hockey. Data for baseline kinematic variables are provided in Table 3.

Table 3. Baseline Body Segment Kinematic (°) Measures

Variable	Sport	Range (min, max)	Mean ± SD	Median	*d* (95% CI)
LTL Angle at Initial Contact	IH	5.33 (8.21, 13.55)	10.28 ± 1.59	10.08	
	vs LAX	7.69 (5.37, 13.06)	9.47 ± 2.64	9.76	-0.38 (-1.27, 0.51)
	vs FH	4.92 (5.66, 10.58)	8.92 ± 2.26	9.73	-0.83 (-1.69, 0.04)
	LAX vs FH				0.23 (-0.95, 1.41)
LTL Angle at Peak KV	IH	8.82 (5.01, 13.83)	9.45 ± 3.00	9.49	
	vs LAX	26.58 (2.65, 29.23)	9.65 ± 6.95	7.64	0.04 (-2.17, 2.24)
	vs FH	10.92 (3.16, 14.08)	9.54 ± 4.68	10.45	0.03 (-1.67, 1.72)
	LAX vs FH				0.02 (-2.98, 3.01)
Peak LTL Angle	IH	11.18 (10.34, 21.52)	14.87 ± 3.60	14.11	
	vs LAX	26.05 (7.85, 33.90)	15.49 ± 7.01	14.00	0.11 (-2.17, 2.40)
	vs FH	18.43 (11.46, 29.90)	21.07 ± 7.61	21.45	1.36 (-1.02, 3.75)
	LAX vs FH				-0.84 (-4.11, 2.44)
KV Angle at Initial Contact	IH	8.59 (-3.36, 5.23)	1.26 ± 3.04	1.79	
	vs LAX	9.59 (-3.71, 5.88)	2.06 ± 3.20	3.01	0.27 (-0.98, 1.52)
	vs FH	5.74 (1.08, 6.82)	3.50 ± 2.41	3.04	0.84 (-0.57, 2.24)
	LAX vs FH				-0.51 (-1.90, 0.89)
Peak KV Angle	IH	19.62 (-2.28, 17.34)	7.05 ± 5.78	8.02	
	vs LAX	22.85 (-1.45, 21.41)	9.61 ± 6.88	9.52	0.42 (-2.13, 2.97)
	vs FH	17.48 (4.28, 21.76)	10.74 ± 7.61	8.45	0.63 (-2.42, 3.68)
	LAX vs FH				-0.17 (-3.40, 3.06)

** Denotes statistical significance; † Denotes clinical significance*
Abbreviations: IH = ice hockey; LAX = lacrosse; FH = field hockey; SD = standard deviation; *d* = Cohen's effect size; CI = confidence interval

Baseline Core Strength Measures

A statistically significant difference existed for average normalized peak isometric trunk flexion force ($P = 0.023$). Subsequent pairwise comparisons displayed that ice hockey had a greater measure than lacrosse (Figure 4), which was accompanied by a clinically significant large effect size. A similar clinically significant large effect size existed for trunk flexion force between ice hockey, and field hockey. No statistically significant difference existed for average normalized peak isometric trunk extension force ($P = 0.389$); however, ice hockey players displayed greater trunk extension force than lacrosse, and field hockey, represented by respective medium, and large effects sizes that were clinically significant. Data for baseline core strength measures are provided in Table 4.

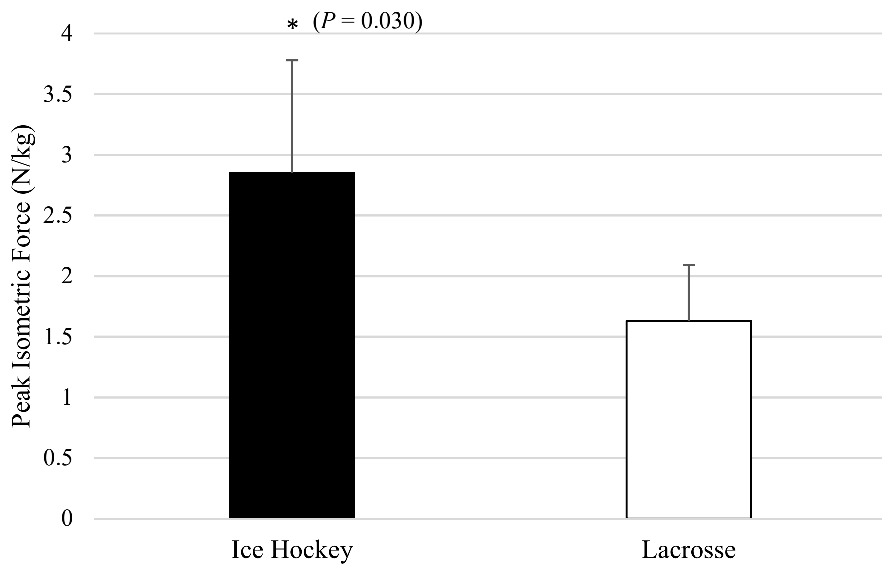

Figure 4. Baseline average median normalized peak trunk flexion force between ice hockey and lacrosse. * *Denotes statistical significance*

Table 4. Baseline Core Strength Measures [Average Normalized Peak Isometric Force (N/kg)]

Variable	Sport	Range (min, max)	Mean ± SD	Median	*d* (95% CI)
Flexion	IH	2.42 (1.33, 3.75)	2.73 ± 0.93	2.85	
	vs LAX	1.31 (1.07, 2.38)	1.64 ± 0.46	1.63	1.62 **(1.34, 1.90)†**
	vs FH	1.80 (0.75, 2.55)	1.57 ± 0.94	1.50	1.35 **(0.90, 1.80)†**
	LAX vs FH				-0.11 (-0.39, 0.16)
Extension	IH	3.85 (1.91, 5.76)	3.63 ± 1.30	3.12	
	vs LAX	4.19 (1.10, 5.28)	2.90 ± 1.26	2.80	0.59 **(0.09, 1.10)†**
	vs FH	2.81 (0.90, 3.70)	2.63 ± 1.32	2.96	0.82 **(0.19, 1.46)†**
	LAX vs FH				-0.23 (-0.81, 0.36)

* *Denotes statistical significance;* † *Denotes clinical significance*
Abbreviations: IH = ice hockey; LAX = lacrosse; FH = field hockey; SD = standard deviation; *d* = Cohen's effect size; CI = confidence interval

Core Endurance Assessment Measures

No statistically significant differences existed for CEA measures (P = 0.283 for sit-ups; P = 0.427 for back extensions; P = 0.592 for side crunches to the right; P = 0.703 side crunches to the left; P = 0.632 for seated trunk twists). However, field hockey players displayed a greater time to self-perceived fatigue for the back extension exercise compared with ice hockey, and lacrosse as evidenced by large effect sizes. Data for CEA measures are provided in Table 5.

Table 5. Core Endurance Assessment Time (s) to Self-Perceived Fatigue

Variable	Sport	Range (min, max)	Mean ± SD	Median	*d* (95% CI)
Sit-Ups	IH	78.82 (37.06, 115.88)	68.95 ± 25.09	61.25	
	vs LAX	69.81 (28.56, 98.37)	56.26 ± 20.43	51.27	0.59 (-8.44, 9.61)
	vs FH	34.22 (36.78, 71.00)	52.28 ± 14.21	50.67	0.79 (-10.30, 11.88)
	LAX vs FH				-0.22 (-9.05, 8.61)
Back Extensions	IH	35.31 (23.56, 58.87)	41.63 ± 9.62	40.19	
	vs LAX	32.28 (33.78, 66.06)	44.79 ± 9.91	40.88	-0.34 (-4.24, 3.56)
	vs FH	69.30 (32.70, 102.00)	62.68 ± 29.36	58.04	-1.35 (-9.53, 6.84)
	LAX vs FH				1.18 (-6.24, 8.60)
Side Crunches-Right	IH	42.38 (8.37, 50.75)	28.12 ± 13.54	28.53	
	vs LAX	29.87 (11.10, 40.97)	26.24 ± 10.17	28.11	0.17 (-4.54, 4.87)
	vs FH	45.32 (10.09, 55.41)	34.78 ± 19.69	36.81	-0.47 (-7.90, 6.96)
	LAX vs FH				0.71 (-5.16, 6.59)
Side Crunches-Left	IH	38.60 (9.18, 47.78)	31.40 ± 10.19	31.44	
	vs LAX	45.13 (13.09, 58.22)	33.82 ± 12.61	33.71	-0.22 (-4.83, 4.40)
	vs FH	20.23 (17.34, 37.57)	30.93 ± 9.42	34.41	0.05 (-4.80, 4.90)
	LAX vs FH				-0.26 (-5.76, 5.24)
Seated Trunk Twists	IH	70.81 (16.28, 87.09)	49.51 ± 18.39	48.38	
	vs LAX	47.72 (27.59, 75.31)	43.74 ± 15.56	39.06	0.36 (-6.37, 7.09)
	vs FH	57.90 (26.80, 84.70)	50.80 ± 25.78	45.84	-0.07 (-10.00, 9.87)
	LAX vs FH				0.41 (-7.95, 8.78)

* *Denotes statistical significance; † Denotes clinical significance*
Abbreviations: IH = ice hockey; LAX = lacrosse; FH = field hockey; SD = standard deviation;
d = Cohen's effect size; CI = confidence interval

Post-Core Endurance Assessment Strength Measures

A statistically significant difference existed for average normalized peak isometric trunk flexion force ($P < 0.001$). Subsequent pairwise comparisons displayed that ice hockey had a greater measure than lacrosse, and field hockey (Figure 5), which were accompanied by clinically significant large effect sizes. No statistically significant difference existed for average normalized trunk extension force ($P = 0.438$). Data for post-CEA strength measures are provided in Table 6.

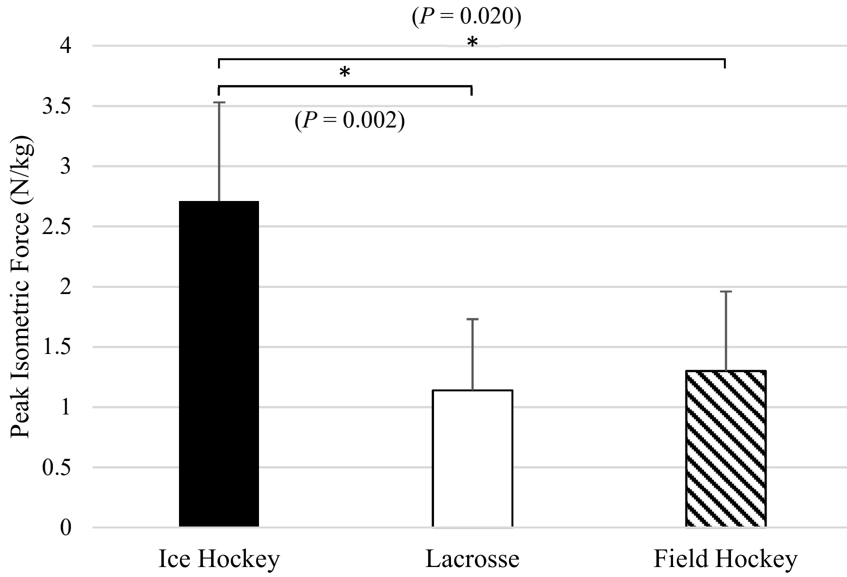

Figure 5. Pairwise comparisons between groups for post-core endurance assessment average median normalized peak isometric trunk flexion force
** Denotes statistical significance*

Table 6. Post-Core Endurance Assessment Core Strength Measures [Average Normalized Peak Isometric Force (N/kg)]

Variable	Sport	Range (min, max)	Mean ± SD	Median	*d* (95% CI)
Flexion	IH	2.75 (1.22, 3.97)	2.82 ± 0.82	2.71	
	vs LAX	1.87 (0.51, 2.38)	1.31 ± 0.59	1.14	2.26 **(1.98, 2.54)**†
	vs FH	1.21 (0.63, 1.83)	1.26 ± 0.66	1.30	2.15 **(1.77, 2.53)**†
	LAX vs FH				-0.08 (-0.36, 0.19)
Extension	IH	4.13 (1.90, 6.03)	3.38 ± 1.34	3.33	
	vs LAX	3.15 (1.70, 4.85)	2.89 ± 1.11	2.63	0.42 (-0.07, 0.90)
	vs FH	3.70 (1.32, 5.02)	2.79 ± 1.61	2.42	0.47 (-0.24, 1.13)
	LAX vs FH				-0.09 (-0.65, 0.48)

** Denotes statistical significance; † Denotes clinical significance*
Abbreviations: IH = ice hockey; LAX = lacrosse; FH = field hockey; SD = standard deviation; *d* = Cohen's effect size; CI = confidence interval

Post-Core Endurance Assessment Kinematic Measures

No statistically significant differences existed for post-CEA kinematic variables ($P = 0.994$ for LTL angle at initial contact; $P = 0.143$ for LTL angle at peak KV; $P = 0.300$ for peak LTL angle; $P = 0.683$ for KV angle at initial contact; $P = 0.253$ for peak KV angle). However, field hockey players displayed a greater LTL angle at peak KV compared with lacrosse, and a greater peak

LTL angle than ice hockey, as evidenced by large effect sizes. Data for post-CEA kinematic variables are provided in Table 7.

Table 7. Post-Core Endurance Assessment Body Segment Kinematic (°) Measures

Variable	Sport	Range (min, max)	Mean ± SD	Median	*d* (95% CI)
LTL Angle at Initial Contact	IH	6.42 (6.67, 13.09)	9.20 ± 1.83	9.16	
	vs LAX	9.72 (4.57, 14.28)	9.11 ± 2.87	9.60	-0.04 (-1.02, 0.94)
	vs FH	1.00 (8.85, 9.86)	9.37 ± 0.41	9.38	0.11 (-0.67, 0.89)
	LAX vs FH				-0.11 (-1.28, 1.06)
LTL Angle at Peak KV	IH	13.85 (5.50, 19.35)	9.64 ± 4.31	8.27	
	vs LAX	19.35 (3.17, 22.52)	8.61 ± 4.93	8.13	-0.23 (-2.09, 1.63)
	vs FH	6.39 (8.77, 15.16)	12.09 ± 3.14	12.22	0.65 (-1.31, 2.62)
	LAX vs FH				-0.81 (-2.92, 1.30)
Peak LTL Angle	IH	15.07 (7.15, 22.22)	15.18 ± 4.83	15.72	
	vs LAX	36.01 (6.72, 42.73)	15.33 ± 9.30	12.78	0.02 (-3.02, 3.06)
	vs FH	18.54 (13.38, 31.92)	21.76 ± 8.77	20.88	1.17 (-1.77, 4.11)
	LAX vs FH				-0.75 (-4.96, 3.46)
KV Angle at Initial Contact	IH	8.38 (-3.74, 4.64)	0.99 ± 2.99	1.48	
	vs LAX	10.49 (-3.89, 6.60)	2.06 ± 3.35	3.05	0.35 (-0.92, 1.62)
	vs FH	5.54 (0.04, 5.59)	1.88 ± 2.52	0.95	0.38 (-1.12, 1.87)
	LAX vs FH				0.06 (-1.40, 1.52)
Peak KV Angle	IH	20.59 (-2.13, 18.46)	5.85 ± 5.76	5.14	
	vs LAX	23.81 (-2.69, 21.12)	10.08 ± 6.67	9.76	0.71 (-1.79, 3.21)
	vs FH	15.50 (2.76, 18.26)	9.53 ± 7.02	8.54	0.65 (-2.31, 3.61)
	LAX vs FH				0.09 (-3.01, 3.18)

* *Denotes statistical significance; † Denotes clinical significance*
Abbreviations: IH = ice hockey; LAX = lacrosse; FH = field hockey; SD = standard deviation; *d* = Cohen's effect size; CI = confidence interval

Chapter 4

DISCUSSION

Core Strength Measures

Our results support the hypothesis that ice hockey players would display greater core performance characteristics than lacrosse, and field hockey players; however these were specific to greater trunk flexion, and extension strength at baseline, and greater trunk flexion strength post-CEA. Core strength is associated with balance[46,47]; therefore, movement patterns inherent to the unique demands for maintaining dynamic balance associated with each sport could explain our trunk strength outcomes. Ice hockey is characterized by skating on a low-friction surface while dynamically balancing on a narrow base of support, which is associated with heightened physical demands that may yield increased core muscle activation.[48]

Increased core muscle activation may be an inherent ACL-tear prevention strategy as it has been shown that those who intentionally activate their core have reduced frontal plane knee motion than those who do not.[49] Additionally, Myer et al[50] described that lower extremity kinematics were improved after examiners provided trunk-position feedback during a tuck-jump circuit, suggesting that activating the core musculature to correctly position the trunk may serve as a means to improve lower extremity mechanics during athletic activity.

Furthermore, increases in core activation have been observed in unilateral balancing tasks with added external perturbations[51] that mirrors scenarios often encountered in ice hockey. Contrastingly, lacrosse, and field hockey entail running on a high-friction surface with a wider base of support, which diminishes emphasis on maintaining balance, and thus core activation. Based on this phenomenon, ice hockey players, who would be expected to have greater measures of balance may, as a direct result, have greater measures of core strength, which has been shown to decrease risk of sustaining a non-contact lower extremity injury.[52] Consequently, Pfile et al[53] found that improving core strength through a four-week core stability program significantly reduced risk factors associated with sustaining an ACL tear. Associations have been found between improvements in core and hip strength.[54,55] The trunk acts as the base to which the extremities attach; therefore, if the core musculature is weak, poor distal segment mechanics will result in, and increase risk of sustaining a lower extremity injury, such as an ACL tear.

The varied physical fitness demands of each sport may also provide insights as to the disparate trunk strength measures elicited from our study. Ice hockey, lacrosse, and field hockey have playing areas of approximately 1,586 m^2 [56], 6,600 m^2 [57],and 5,027 m^2 [58], respectively, indicating that lacrosse and field hockey are more endurance-based sports due to the amount of distance athletes must travel during play. Oppositely, ice hockey is a shorter-distance game marked by rapid accelerations and decelerations[59] which puts the physiological emphasis on muscular power and force production. Häkkinen and Myllylä[60] found that power athletes had significantly greater peak force production capabilities compared with those participating in endurance-based sports, which parallels our findings. Consequently, individuals capable of greater force production also display a lesser rate of force development, proposing an ability to generate force more quickly. Higher peak force production and faster neuromuscular activation could be indicative of a greater resilience to external perturbations during non-contact athletic movements, not allowing the trunk to sway outside of neutral alignment which is a risk factor associated with higher ACL-tear rates.[11,12,53] Stronger core musculature will maintain the trunk over the pelvis and help to prevent ground reaction forces from heightening knee valgus angle.

Reduced core strength may be problematic specifically for lacrosse players. Chaudhari et al[61] found that during a cutting task women who held a lacrosse stick on the side of the plant-leg had a significantly higher peak knee valgus moment than when held on the opposite side. Therefore, the constrained plant-side arm may not be used as a stabilizer to correctly position the trunk and when in combination with reduced core strength, the athlete may not be capable of offsetting the forces that laterally displace the trunk and could be at increased risk of sustaining an ACL tear. Despite also carrying a stick, greater core strength measures in ice hockey players could make them more resistant to the forces that laterally shift the trunk which would decrease the risk of injuring the ACL.

Core Endurance Assessment Measures

Even though no statistically significant differences existed for the results of the CEA, body positioning during play of each sport could explain the large effect size for the back extension exercise. Field hockey players had a longer time to self-perceived fatigue than both ice hockey, and lacrosse. Ice hockey and field hockey are both played while forward-flexing the trunk, with the stick angled towards the ground. Although they have similar positions, field hockey is played with shorter sticks than ice hockey, which will cause field hockey players to activate their trunk extensor muscles while maintaining a greater forward-flexion angle than ice hockey, and ultimately increase endurance time to fatigue.[62]

In contrast to the playing styles of ice hockey and field hockey, women's lacrosse is played in an upright position with the stick held in front of the body. The posterior trunk muscles would not be required to sustain the same amount of long-term effort during play and would therefore produce a lesser back extension endurance time than field hockey. A more vertical trunk position in the sagittal-plane has been identified as a risk factor for non-contact ACL tears due to increased knee extensor moments.[55] Field hockey players will be able to spend more time in a forward-flexed trunk position because of superior muscular endurance which could contribute to lower ACL injuries in field hockey compared with lacrosse. It may be beneficial for lacrosse to be played with more trunk flexion but the athletes may not be able to sustain this position due to decreased back extension endurance. Despite ice hockey and lacrosse players having similar back extension endurance times, ice hockey players, as previously discussed, play with the trunk in a more forward-flexed position than lacrosse, which would inherently assist in decreasing the knee extensor moment while playing and contribute to lower ACL-tear risk.

Although inconsistent with our findings, previous literature suggests that decreased core muscle endurance could lead to increases in LTL angle and shift the center of mass of the body into a position in which the knee is at-risk for injury. Running-induced fatigue significantly increases mediolateral trunk sway[63] so those with lesser measures of core endurance may then be at increased risk for sustaining an ACL tear since the onset of core fatigue will alter the athlete's kinematics. Therefore, a more functional, sport-specific CEA may elicit differing body segment kinematic measures among groups in future research.

Body Segment Kinematic Measures

Contrary to our hypotheses regarding baseline and post-CEA body segment kinematics variables, no significant differences existed among groups. Pfile et al[53] described similar results in which trunk kinematic variables were not significantly different between two groups who were exposed to unique exercise programs aimed at reducing trunk motion during a single-leg vertical drop landing. Accordingly, Martinez et al[64] found that during a single-leg vertical drop jump there were no correlations between trunk strength and lower extremity kinematics, suggesting that the landing task may have been the causal factor. Our study included elite, healthy athletes who may not have been influenced by the perturbations provided from the 30-cm single-leg vertical drop landing height, despite its frequency of use in the literature.[28,32,65] Future studies should investigate landing kinematics from a greater height, or add a multi-planar task to better replicate functional athletic movements that athletes perform during play.

Although our study did not examine sagittal plane trunk and knee positioning, previous literature has described kinematic profiles similar to the body positioning of women's lacrosse players that inherently put them at a higher risk for sustaining an ACL tear. In a comparison between women's lacrosse and field hockey players, Braun et al[65] found that lacrosse players landed with the trunk in a more upright position with less knee flexion angle compared with field hockey players, which, as previously discussed, creates increased anterior-tibial shear forces and knee extensor moments.[55] Similarly, it has been presented that those who landed in an upright position had significant increases in ground reaction forces through the lower extremity and increased quadriceps activation compared with those who landed with the trunk in a forward-flexed position.[66,67] Landing with a more upright trunk increases stress on the ACL because it limits the ability of the hamstrings to pull the tibia posteriorly.[65] Thus, increasing trunk and knee flexion angle during knee-joint loading is an ACL-tear prevention mechanism. Future research should analyze sagittal plane motion to gain a larger overview of how multi-planar trunk positioning affects knee-injury risk.

As evidenced by large effect sizes at baseline and post-CEA, field hockey players consistently displayed greater LTL, and KV angles, indicative of poorer landing mechanics. Our data would suggest that field hockey players should be at a higher risk to sustain an ACL tear than ice hockey and lacrosse athletes; however, the single-leg vertical drop landing is a task that is novel to field hockey athletes. Jumping, and subsequently landing rarely occur in field hockey[65] since the ball is played almost exclusively on the ground, whereas the opposite is true in lacrosse. Therefore, field hockey players could have less neuromuscular control of the trunk, hip, and knee during a loading task since it is foreign to them, thus explaining the inconsistencies with our hypothesis that lacrosse would have the greatest measures of LTL, and KV angle among groups.

Post-CEA peak KV angle was higher in lacrosse compared with ice hockey, displayed by a medium effect size of 0.707 and a median difference of 4.623°. Despite not meeting our thresholds for statistical significance, a difference of this magnitude in a clinical setting could be the reason for sustaining an ACL tear during an athletic maneuver. During skating ice hockey players recruit the gluteus maximus by externally rotating and extending the hip[68], which has been associated with preventing increased KV angle during joint-loading tasks.[49] This is consistent with the findings of Willson et al[69] who displayed that hip external rotation strength was associated with frontal plane knee positioning during a single-leg squat. The gluteus maximus will naturally be strengthened through skating and add stability to the hip joint, making ice hockey players more resistant than lacrosse players to the KV angles that are associated with ACL tears.

Limitations

Several limitations existed in our study. We examined an elite athlete population who may not have been challenged enough by the 30-cm box height during the landing task to elicit differences among groups. Athletic activity is a complex, multi-planar movement system that imposes external forces on the body in many directions. The landing task was uni-planar from a relatively low height and the perturbations imparted on the body may not have replicated the magnitude of external forces that athletes experience during play.

The height of the hop with which the participants left the box, and arm motion upon landing were not controlled and could have affected the results. In addition, all landing trials were performed barefoot, a novel task for the athletes since all training and conditioning is done wearing athletic shoes. Future research should explore a more functional task, such as cutting, while wearing standardized footwear to better assess body segment kinematics.

More advanced technology was not used for data collection in this study. Body segment kinematic variables were assessed using 2-dimensional video analysis which is not of the same caliber as 3-dimensional analysis, despite being shown to be comparable.[33,34] By not accounting for hip or knee rotation, 2-dimensional KV angle may not be wholly translatable to that of 3-dimensional analysis. However, 2-dimensional analysis is an easy, relatively valid method in a clinical setting to identify patients who may be at risk for suffering an ACL tear. Furthermore, a force plate was not used to collect kinetics during the single-leg landing task which could have complemented the kinematic data. Also, a machine like an isokinetic dynamometer was not used to evaluate rate of force development of the core musculature which could have been used as a variable in examining how quickly subjects were able to activate the core during landing.

We are not familiar with the injury prevention interventions or strength and conditioning programs in which the athletes were enrolled which could have influenced the participant's preparedness for each task performed during testing. Participants in training programs focused on plyometrics and power will produce different experimental outcomes compared with those who have a more endurance-based exercise regimen. Furthermore, the core strength and endurance assessments were based on the participant's willingness to reach maximum effort and may have not been representative of a truly maximum exertion.

Conclusions

The results of our study suggest that core strength is a modifiable risk factor associated with ACL tears. The core acts as the base to which the extremities attach for movement and is a proximal stabilizer for distal segments. The outcomes indicate that because of greater core strength measures ice hockey players may be more resistant to the external perturbations that tend to shift the trunk outside of neutral alignment and increase knee valgus moment. Core strengthening programs should be explored among women's sports similar to ice hockey, lacrosse, and field hockey as a means of reducing the risk of sustaining an ACL tear.

APPENDIX A

Thesis Proposal

Purpose

Approximately 250,000 anterior cruciate ligament (ACL) tears occur each year in the United States[1,2] and 80% of those who sustain an ACL tear develop knee complications such as osteoarthritis or meniscal tears 5-15 years post-injury.[4] Anterior cruciate ligament tears frequently occur with non-contact mechanisms that load the knee, such as landing or sudden changes in direction.[3,5,6] During these events, the most stress is placed on the ACL when there is excessive knee valgus.[7,8] Women intrinsically have a higher knee valgus angle due to their wider pelvises which contributes to an ACL-tear risk that is three times higher than their male counterparts[9]; however a myriad of other extrinsic factors may underpin discrepancies in ACL injury incidence rate among women's sports. Consequently, there is a disparity in ACL-tear incidence among women's ice hockey, lacrosse, and field hockey, which have associated injury rates of 0.02, 0.23, and 0.11 per 1000 athletic exposures, respectively.[10]

It has been postulated that decreased core endurance is a risk factor for suffering an ACL tear.[11,12] The core is defined as the ensemble of active structures in the torso and pelvis that contribute to lumbopelvic and trunk stability. The core acts as a stable base to which the extremities attach for dynamic movements.[14–16] Evidence demonstrates that fatigued muscles have a hindered capacity to stabilize joints when exposed to external perturbations[17], and thus it can be assumed that fatigued core musculature will respond in a similar manner during high impact tasks commonly associated with ACL injury. Reduced core endurance could cause extraneous trunk movement, thus shifting the individual's center of mass and causing altered body segment kinematics which may exacerbate knee-valgus forces, increasing ACL-tear risk[21]; however, there is a scarcity of information detailing the effect of core fatigue on body segment kinematics during dynamic tasks that load the knee.

Greater measures of core endurance have been associated with improved postural stability.[24] Due to the nature of the repetitive single-leg stance on a narrow base of support on a low-friction surface, ice hockey players may inherently have greater postural stability, and therefore core endurance, which makes them less susceptible to ACL injuries than lacrosse and field hockey players. However, comparisons of core endurance and its effects on body segment kinematics upon knee loading in these populations have not been previously investigated; therefore, the purpose of this experiment is to study this phenomenon.

Aim 1: To compare baseline lateral trunk lean, and knee valgus angles following joint loading among women's ice hockey, lacrosse, and field hockey players.

Hypothesis 1a: Women's ice hockey players will have less lateral trunk lean at initial contact, and less lateral trunk lean at peak knee valgus angle than lacrosse, and field hockey players.

Hypothesis 1b: Women's ice hockey players will have less knee valgus angle at initial contact, and less peak knee valgus angle than lacrosse, and field hockey players.

Aim 2: To compare core strength and endurance measures among women's ice hockey, lacrosse, and field hockey players.

Hypothesis 2: Women's ice hockey players will have greater core strength, and endurance measures than lacrosse, and field hockey.

Aim 3: To compare lateral trunk lean, and knee valgus angles following joint loading after the onset of core fatigue among women's ice hockey, lacrosse, and field hockey players.

Hypothesis 3a: Women's ice hockey players will have less lateral trunk lean at initial contact, and less lateral trunk lean at peak knee valgus angle than lacrosse, and field hockey players.

Hypothesis 3b: Women's ice hockey players will have less knee valgus angle at initial contact, and less peak knee valgus angle than lacrosse, and field hockey players.

Aim 4: To assess associations between core performance measures, and body segment kinematics following knee joint loading.

Hypothesis 4: Greater measures of core strength and endurance will be associated with lesser lateral trunk lean, and knee valgus angles.

Plan

The study is a cohort experimental design. We will recruit Penn State University varsity women's ice hockey, lacrosse, and field hockey players. The sequential procedures are as follows:

1. Anthropometric and demographic data will be recorded.
2. A two-dimensional video camera system will record frontal plane views of single-leg vertical drop landings from a 30-cm box onto the participant's non-dominant leg. Female athletes have been shown to have increased ACL-tear rates on the non-dominant leg[29,30] caused by decreased joint stabilization from reduced neuromuscular control.[31] The average of three trials will determine lateral trunk lean, and knee valgus angles. ImageJ software (http://rsb.info.nih.gov/ij/) calculates body segment kinematics.

3. A Nicholas Manual Muscle Tester™ handheld dynamometer (Lafayette Instrument Company, Lafayette, Indiana) measures peak maximum voluntary isometric trunk flexion, and extension force from three trials.
4. While wearing a weighted vest adjusted to 15% of body mass, participants will perform a circuit of exercises on a glute-ham bench intended to fatigue the core musculature in the sagittal, frontal, and transverse planes (sit-ups, prone back extensions, side-lying lateral crunches, and seated trunk twists). Each exercise will be performed to a 36-beats-per-minute metronome cadence until they cannot continue, cannot return to the start position for two or more consecutive beats, or they break cadence with the metronome for four consecutive beats. Dynamic core endurance will be quantified by the length of elapsed time for the participant to reach self-perceived fatigue for each respective exercise.
5. A second handheld dynamometer assessment determines the amount of core fatigue.
6. Single-leg vertical drop landing measurements are repeated immediately following the core endurance protocol.

Data Analysis

A separate one-way analysis of variance will compare mean differences for core performance, and body segment kinematic variables among groups with Tukey's Honestly Significant Difference used for pairwise comparisons. Pearson's correlation coefficient will evaluate associations between core performance, and body segment variables. $P \leq 0.05$ will denote statistical significance.

Outcomes

The intended outcome of this study is to identify a modifiable risk factor for ACL tears that contributes to the discrepancy in injury rates among women's ice hockey, lacrosse, and field hockey players. If it is discovered that lesser core performance measures are associated with increased lateral trunk lean and knee valgus angles, interventions can be applied to improve body segment kinematics following knee loading in an effort to reduce the incidence, and prevalence of ACL tears that occur in these female collegiate sports.

APPENDIX B

Recruitment Flyer

PENNSTATE

Athletic Training Research Laboratory

Research Volunteers Needed

Are you interested in learning more about core fatigue and landing performance?

If so, you may be interested in participating in our research study at Penn State.

Measurements: Core strength, dynamic core endurance, as well as landing performance

Purpose: To study the relationship between core fatigue and landing mechanics

One 30-minute session at the Athletic Training Research Laboratory in 26 Recreation Building, the Rec Hall Varsity Weight Room, or the Pegula Ice Arena Varsity Weight Room

Requirements:

- Currently on Penn State's women's ice hockey, lacrosse, or field hockey teams
- Between the ages of 18-35
- Physically fit to participate in team activities
- No major knee injuries or surgeries in the past

For more information, contact Matt Armistead at
mja29@psu.edu or 302-757-2624

Matt Armistead, John Vairo, and S. John Miller, Dov Bader, Kathryn Gloyer, and Wayne Sebastianelli

Department of Kinesiology

APPENDIX C

Pre-Participation Screening Questionnaire

PENNSTATE

Athletic Training Research Laboratory

Participant Name ______________________________

These questions will help us to determine if you are eligible to be a participant in our study. Please answer either yes or no to each question:

1. Are you between the ages of 18-35?
   [ ] YES [ ] NO

2. Have you ever had a knee injury on either leg?
   [ ] YES [ ] NO

   a. If yes, mark which leg(s) you have had a knee injury to?
      [ ] Dominant [ ] Non-Dominant

   b. If yes, name or describe your knee injury to the best of your ability.
      ____

3. Do you currently have a lower extremity injury that is causing missed participation in your sport?
   [ ] YES [ ] NO

4. Do you smoke?
   [ ] YES [ ] NO

5. Have you ever smoked?
   [ ] YES [ ] NO

6. Are you pregnant?
   [ ] YES [ ] NO

APPENDIX D

Participant Informed Consent Form

PENNSTATE

Athletic Training Research Laboratory

CONSENT FOR RESEARCH
The Pennsylvania State University

Title of Project: Core Performance Measures and Body Segment Kinematics Following Knee Joint Loading Among Female Collegiate Athletes
Principal Investigator: Matthew Armistead
Address: 29 Recreation Building, University Park, PA 16802
Telephone Number: 302-757-2624
Advisor: John Vairo
Advisor Telephone Number: 814-865-2725

Subject's Printed Name: ____

Subjects' Email Address: ____

We are asking you to be in a research study. This form gives you information about the research.

Whether or not you take part is up to you. You can choose not to take part. You can agree to take part and later change your mind. Your decision will not be held against you.

Please ask questions about anything that is unclear to you and take your time to make your choice.

1. Why is this research study being done?

We are asking you to be in this research because you are healthy, physically active and between the ages of 18-35 years old. You have no history of major knee or low back injuries or surgeries. This research is being done to find out the relation between the core muscles of the body and lower extremity injuries. Additionally, we want to see if there are any differences in landing or core endurance between various women's sports. Approximately 30-45 people will take part in this research study at Penn State.

2. What will happen in this research study?

If you choose to participate in this research study, you will be asked to perform the following procedures:

- 2 Single-leg landing tasks
- 2 Core strength assessment
- Core exercises

3. What are the risks and possible discomforts from being in this research study?

- The discomforts and risks with participation in this type of research study are minimal.
- The tests used are within expected ranges for physically active people.

- To lessen the chance of injury, you will also be shown how to properly perform every task in the experiment.
- Possible discomfort may consist of delayed onset muscle soreness 48 to 72 hours following testing. As with any research study, it is possible that unknown harmful effects may happen. However, the chance for injury in this type of research study is minimal and includes muscle strains, ligament sprains and bone fractures.
- We will take every possible effort to watch for and help prevent against any discomforts and risks.
- There is a risk of loss of confidentiality if your information or your identity is obtained by someone other than the investigators, but precautions will be taken to prevent this from happening. The confidentiality of your electronic data created by you or by the researchers will be maintained to the degree permitted by the technology used. Absolute confidentiality cannot be guaranteed.

4. What are the possible benefits from being in this research study?

4a. What are the possible benefits to you?

There is no direct benefit to you from participating in this research study.

4b. What are the possible benefits to others?

The benefits to society include recognizing potential advantages of core endurance training in female athletes for the reduction of lower extremity injury.

5. What other options are available instead of being in this research study?

You may decide not to participate in this research. However, there are no known alternative procedures used to answer the research questions of this study.

6. How long will you take part in this research study?

If you agree to take part, the one testing session will take you 30 minutes to complete. All testing will take place in the Athletic Training Research Laboratory.

7. How will your privacy and confidentiality be protected if you decide to take part in this research study?

Efforts will be made to limit the use and sharing of your personal research information to people who have a need to review this information.

- Your participation in this research study is strictly confidential. All research records from your participation in this study will be kept confidential similar to medical records at your doctor's office or hospital.
- All records will be secured in locked file cabinets at the Athletic Training Research Laboratory. A list that matches your name with your code number and all video will be stored in a password protected file.
- In the event of any publication resulting from this research study, no personally identifiable information will be disclosed. Penn State's Office for Research Protections, the Institutional Review Board and the Office for Human Research Protections in the Department of Health and Human Services may review records related to this research study.

We will do our best to keep your participation in this research study confidential to the extent permitted by law. However, it is possible that other people may find out about your participation in this research study. For example, the following people/groups may check and copy records about this research.

- The Office for Human Research Protections in the U. S. Department of Health and Human Services
- The Institutional Review Board (a committee that reviews and approves research studies) and
- The Office for Research Protections.

Some of these records could contain information that personally identifies you. Reasonable efforts will be made to keep the personal information in your research record private. However, absolute confidentiality cannot be guaranteed.

8. What happens if you are injured as a result of taking part in this research study?

- In the unlikely event you become injured as a result of your participation in this research study, medical care is available. If you become injured during testing procedures the investigators listed on this informed consent form will provide you with appropriate first aid care and instruct you on proper steps for follow-up care.
- If you were to experience any unexpected pain or discomfort from participating in this research study after leaving the Athletic Training Research Laboratory please contact Matt Armistead at 302-757-2624. If you cannot reach Matt Armistead please leave him a voicemail and contact your doctor.
- Since you are a Penn State student, if you cannot reach Matt Armistead or your doctor, please leave them voicemails and contact Penn State University Health Services at: Student Health Center University Park PA 16802 814-865-6556.
- It is the policy of this institution to provide neither financial compensation nor free medical treatment for research-related injury. By signing this document, you are not waiving any rights that you have against The Pennsylvania State University for injury resulting from negligence of the University or its investigators.

11. What are your rights if you take part in this research study?

Taking part in this research study is voluntary.

- You do not have to be in this research.
- If you choose to be in this research, you have the right to stop at any time.
- If you decide not to be in this research or if you decide to stop at a later date, there will be no penalty or loss of benefits to which you are entitled.

12. If you have questions or concerns about this research study, whom should you call?

Please call the head of the research study (principal investigator), Matt Armistead at 302-757-2624 if you:

- Have questions, complaints or concerns about the research.
- Believe you may have been harmed by being in the research study.

You may also contact the Office for Research Protections at (814) 865-1775, ORProtections@psu.edu if you:

- Have questions regarding your rights as a person in a research study.
- Have concerns or general questions about the research.
- You may also call this number if you cannot reach the research team or wish to offer input or to talk to someone else about any concerns related to the research.

<u>INFORMED CONSENT TO TAKE PART IN RESEARCH</u>
<u>Signature of Person Obtaining Informed Consent</u>

Your signature below means that you have explained the research to the subject or subject representative and have answered any questions he/she has about the research.

______________________________ __________ __________________________

Signature of person who explained this research   Date   Printed Name

(Only approved investigators for this research may explain the research and obtain informed consent.)

<u>Signature of Person Giving Informed Consent</u>

Before making the decision about being in this research you should have:

- Discussed this research study with an investigator,
- Read the information in this form, and
- Had the opportunity to ask any questions you may have.

Your signature below means that you have received this information, have asked the questions you currently have about the research and those questions have been answered. You will receive a copy of the signed and dated form to keep for future reference.

<u>Signature of Subject</u>

You must be 18 years of age or older to take part in this research study.

By signing this consent form, you indicate that you voluntarily choose to be in this research and agree to allow your information to be used and shared as described above.

___________________________	__________	__________________________
Signature of Subject	Date	Printed Name

Optional part(s) of the study
In addition to the main part of the research study, there is another part of the research. You can be in the main part of the research without agreeing to be in this optional part.

<u>Optional Storage of Video Recordings for Future Research</u>
In the main part of this study, we are collecting video recordings that contain identifiable information from you. If you agree, the researchers would like to maintain these video recordings for future research or to be used in publications or at presentations.

- Any future studies may be helpful in understanding the relation between core fatigue and knee injury risk.
- It is unlikely that any future studies will have a direct benefit to you.

Your video recordings will be labeled with a code number.

- These recordings will be stored in a password protected file on the primary investigator's computer and the Box cloud storage software.
- The length of time they will be used is unknown.
- You will be free to change your mind at any time.
- You should contact the principal investigator if you wish to withdraw your permission for your recordings to be used for future research or publicly. The recordings will then be destroyed and not used for future research studies or shown publicly.

You should **<u>initial</u>** below to indicate what you want regarding the storage your video recordings for future research studies.
a. Your identifiable video recordings may be stored and used for future research studies to learn about the core and its relation to lower extremity injury.
______ Yes   _____ No

b. Your identifiable video recordings may be shared publicly at presentations or in publications.
______ Yes   _____ No

<u>Signature of Person Obtaining Informed Consent</u>

Your signature below means that you have explained the optional part(s) to the research to the subject or subject representative and have answered any questions he/she has about the research.

________________________	__________	________________________
Signature of person who explained this research	Date	Printed Name

Signature of Person Giving Informed Consent
<u>Signature of Subject</u>

By signing below, you indicate that you have read the information written above and have indicated your choices for the optional part(s) of the research study.

________________________	__________	________________________
Signature of Subject	Date	Printed Name

APPENDIX E

IRB Approval Letter

PENNSTATE

IRB Program
Office for Research Protections

Vice President for Research
The Pennsylvania State University
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APPROVAL OF SUBMISSION

Date: August 9, 2017

From: Courtney Whetzel, IRB Analyst

To: Matthew Armistead

Type of Submission:	Initial Study
Title of Study:	Associations between Dynamic Core Endurance and Body Segment Kinematics upon Knee Joint Landing in Female Athletes
Principal Investigator:	Matthew Armistead
Study ID:	STUDY00007667
Submission ID:	STUDY00007667
Funding:	Not Applicable
IND,IDE, or HDE:	Not Applicable
Documents Approved:	• Core Fatigue-Landing Consent Form (0.07), Category: Consent Form • Core Fatigue-Landing Data Collection Instruments.docx (0.02), Category: Data Collection Instrument • Core Fatigue-Landing Protocol (0.04), Category: IRB Protocol • Core Fatigue-Landing Recruitment Flyer (0.04), Category: Recruitment Materials • Core Fatigue-Landing Screening Questions (2), Category: Recruitment Materials
Review Level:	Expedited
IRB Board Meeting Date:	8/9/2017

On 8/9/2017, the IRB approved the above-referenced Initial Study. This approval is effective through 8/8/2018 inclusive. You must submit a continuing review form with all required explanations for this study at least 45 days before the study's approval end date. You can submit a continuing review by navigating to the active study and clicking 'Create Modification / CR'.

If continuing review approval is not granted before 8/8/2018, approval of this study expires on that date.
To document consent, use the consent documents that were approved and stamped by the IRB. Go to the Documents tab to download them.

In conducting this study, you are required to follow the requirements listed in the Investigator Manual (HRP-103), which can be found by navigating to the IRB Library within CATS IRB (http://irb.psu.edu). These requirements include, but are not limited to:

- Documenting consent
- Requesting modification(s)
- Requesting continuing review
- Closing a study
- Reporting new information about a study
- Registering an applicable clinical trial
- Maintaining research records

This correspondence should be maintained with your records.

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