Trained Neuromechanical Adaptations Associated with ACL Injury Prevention Programs.

by

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A dissertation submitted in partial fulfillment
of the requirements for the degree of
Doctor of Philosophy
(Kinesiology)
in The University of Michigan
2011

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Acknowledgements

First and foremost, I would like to extend a heartfelt thank you to my advisors, Dr. Riann Palmieri-Smith and Dr. Scott McLean. I am not sure any words I put on this page will do justice the thanks and appreciation I owe you. I have gained considerable respect for both of you during this process. I will be forever grateful for the encouragement, feedback and guidance you have provided me throughout my time here at Michigan. I truly do appreciate the direction you have provide me and cannot thank you enough for taking the time to be my mentors. Thank You.

To the members of my dissertation committee, thank you. To Dr. Richard Hughes and Dr. Ron Zernicke, I have tremendous respect for you both and I would like to extend a sincere thank you for all of your knowledge and experience that helped make this possible. I have truly learned a great deal from this experience and I hope to depart Michigan with some of your wisdom.

Thank you lab members past and present. I appreciate your encouragement and support. Without all your help this would not have been possible. I truly appreciate you pitching in with a helping hand when I needed it. I hope I can be there to lend a helping hand when you need it, too. Thank you.

Mark and Priya, without you both I would have no results. I truly owe you a sincere thank you for helping me out with Matlab code. You have saved me hours and hours of frustration and for that I am forever grateful.

Thank you to all the undergraduate students who have come through the lab. There are too many to name and I would not want to leave anyone out so I will not try to mention everyone who deserves praise. I think you know who you are. Without your help I would not have made it through this project. You were a bigger help than you can imagine, thank you.

Finally, I would like to thank my family. Without your emotional and financial support this would not have been possible. Thank you for the encouragement, understanding and patience. I cannot say enough. Thank you and without you I would not have made it.

Thank you.

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ABSTRACT

Trained neuromechanical adaptations associated with ACL injury prevention programs.

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Anterior cruciate ligament (ACL) injury is the largest single problem in orthopedic sports medicine. Injury prevention protocols have been developed to target the reduction of ACL injury risk during dynamic landings. The current prevention programs are purported to promote successful neuromechanical modifications through adaptation of both lower limb neuromuscular control strategies and joint biomechanics. In spite of these ongoing efforts, however, ACL injury rates and their associated sex disparity have endured. The intent of this dissertation was to assess and potentially improve the effectiveness of the current injury prevention model. Aim one assessed the relations between neuromuscular control strategies and knee joint biomechanics during unilateral landings. Increased quadriceps activation was found to coincide with greater sagittal plane knee kinetics during unilateral jump landings. Aim two compared lower limb joint biomechanical adaptations between unilateral and bilateral landings following a standard neuromuscular training program. It was demonstrated that trained adaptations were only evident during bilateral landings, and unilateral and bilateral landings presented substantially different lower limb biomechanical profiles. Aim three examined the extent to which core stability and plyometric components, used as single modalities, can modify “high- risk” landing biomechanics, as compared to standard neuromuscular and no training models. Plyometric exercises, used in isolation, have the ability to modify hip and knee biomechanics, but only during bilateral landings. The standard neuromuscular training model, however, displayed the potential to promote biomechanical adaptations during unilateral landings. It may be to promote lower limb biomechanical adaptations during unilateral landings future prevention modalities should combine two or more training components to maximize potential benefits. Finally, aim four examined the changes in neuromuscular control strategies that coincide with modifications in joint biomechanics elicited during unilateral landings following isolated core stability, plyometric, standard neuromuscular and no training programs. Core stability and plyometric training were found to produce trained modifications of quadriceps and hamstring activation patterns that predict changes of lower limb sagittal plane loading and frontal plane knee kinematics. It appears that inclusion of both core stability and balance, and plyometric exercises may be necessary to promote a “safer” knee neuromechanical profile.

CHAPTER 1

Introduction

Anterior cruciate ligament (ACL) injury is the largest single problem in orthopedic sports medicine[191], precipitating both extensive short- and long-term debilitation.[81] This clinical dilemma is further complicated by an unexplained sex disparity in injury rates, with women suffering a greater percentage of non-contact ACL injuries.[10] The mechanisms of ACL injury and its potential to be sex-dimorphic have been hypothesized to arise from a combination of both modifiable and non-modifiable risk factors.[81, 98, 209] Injury prevention protocols currently target high-risk lower limb neuromechanics elicited during landings, as they are amenable to training[17], demonstrate sex-dependence[140, 143, 195], and prospectively predict ACL injury risk.[98, 248] Injury prevention programs, while still in their relative infancy, have been purported to promote successful neuromechanical modifications during dynamic landings.[95, 99] These resultant neuromechanical adaptations are achieved through successful modification of both lower limb neuromuscular control strategies[231, 249] and/or joint biomechanics.[44, 90, 158] In spite of these ongoing efforts, however, ACL injury rates and their associated sex disparity have endured. This issue, in part, may stem from limited insight into the explicit relationships between neuromuscular control and biomechanical factors. Understanding which specific muscle groups should be targeted within injury prevention modalities to obtain a reduction in high-risk biomechanical outcomes would focus current training programs and potentially help reduce injury risk.

Current ACL injury prevention strategies are comprised of a series of specific training modalities (core stability/balance, plyometric, resistance, and speed), which reportedly promote safer lower limb neuromechanical profiles.[95, 156, 159] The resultant training modifications, however, vary across prevention programs and potentially stem from the specific training modalities used.[157] Both the plyometric and core stability components, when combined with resistance training, have been shown to produce favorable adaptations in lower limb neuromechanics.[157] It has not been established, however, if similar modifications can be achieved when these components are used in isolation. If shown to be true, then safe neuromechanical profiles could be successfully achieved within a more compact and efficient training model, addressing compliance issues that are a known limitation of current strategies.[160] Ultimately, this may increase effectiveness of ACL injury prevention strategies and coincide with a reduction in the injury rate.

While identifying the specific components of ACL injury prevention programs that improve lower limb neuromechanics is critical to decreasing injury rates, ensuring the modifications are effectively retained during actual sports movements is equally paramount. Assessment of current ACL injury prevention efforts has been based solely on the ability to modify lower limb neuromechanics during overly-simplistic, bilateral landing movements. Currently, little is known regarding whether trained neuromechanical adaptations are possible for unilateral landings[157], despite the fact that they comprise approximately 70% of actual sports landings, are a common vehicle for

ACL injury[29, 100 167], and display significant joint biomechanical differences compared to bilateral landings.[63, 163, 176] With the above facts in mind, increased ACL injury prevention success may be achieved from neuromuscular training strategies that promote neuromechanical modifications during more realistic sports landing maneuvers. Elucidating the ability of current prevention strategies to achieve these outcomes during a single-leg-landing thus provides a critical and necessary first step.

SPECIFIC AIM 1:

To examine the relation between explicit lower limb neuromuscular control strategies and knee joint biomechanics elicited during unilateral landings. Specifically, this study aimed to determine whether lower limb muscle activation patterns were associated with high-risk knee joint biomechanics. To test this aim, both lower extremity muscle activation and knee joint biomechanical data were quantified and evaluated during a series of unilateral landings.

Hypotheses:

There is a significant association between explicit lower-limb neuromuscular control strategies and knee joint biomechanics during unilateral landings.

Subhypothesis 1: Higher levels of vastus lateralis activation are associated with higher peak stance knee flexion moment, abduction angle and moment, and anterior knee joint reaction force.

Subhypothesis 2: Higher levels of lateral and medial hamstring activation are associated with higher peak stance knee flexion angle and moment, and lower anterior knee joint reaction force.

Significance: Understanding how neuromuscular control strategies are linked to joint biomechanical outcomes allows future injury prevention efforts to target explicit muscle groups that may predict a reduction in high-risk lower limb joint biomechanics following training.

SPECIFIC AIM 2:

To compare the lower-limb biomechanical adaptations between uni- and bi-lateral landings following a standard six-week neuromuscular training program. Specifically, this study aimed to determine whether training-induced adaptations realized in bilateral landings were maintained during unilateral landings. To test this aim, lower extremity biomechanics were assessed during a series of uni- and bi-lateral landings both prior to and immediately following a standard neuromuscular training protocol.

Hypotheses:

Following a standard six-week neuromuscular training program, significant lower limb biomechanical adaptations realized during bilateral landings is not be apparent during unilateral landings.

Subhypothesis 1: Participants significantly increase initial contact and peak stance hip and knee flexion angles, and decrease peak stance hip adduction and knee abduction angles during the bilateral landings following a standard neuromuscular training program.

Subhypothesis 2: During unilateral landings, no significant training-induced biomechanical adaptations are evident.

Significance: Determining whether current prevention methods produce training adaptations during unilateral landings, which are more representative of a non-contact

ACL injury scenario, may help improve the future prevention model and ultimately reduce injury rates.

SPECIFIC AIM 3:

To compare the lower limb biomechanical adaptations immediately and six weeks following isolated core stability/balance, plyometric and standard neuromuscular, and no training programs. Specifically, this study aimed to examine the extent to which core stability/balance and plyometric training, when used as single training modalities, modified/reduced "high-risk" landing biomechanics compared to the standard training model. To test this aim, lower extremity biomechanics were assessed during a series of uni- and bi-lateral landings prior to and immediately following the respective injury prevention protocols.

Hypotheses:

All athletes completing an injury prevention protocol (core stability and balance, plyometric and standard neuromuscular) exhibit significant alterations in sagittal plane lower limb biomechanics, while only the core stability/balance and standard neuromuscular participants display significant adaptations of frontal plane lower limb biomechanics following training.

Subhypothesis 1: All training (core stability and balance, plyometric and standard neuromuscular), but not the no training group, display significantly greater peak hip and knee flexion angles and reduced peak flexion moments immediately following completion of the respective training protocols.

Subhypothesis 2: Only the core stability/balance and standard neuromuscular groups display significantly reduced peak hip adduction angle and moment following training.

Subhypothesis 3: Only the plyometric and standard neuromuscular groups substantially reduce knee abduction angle and moment following training.

Significance: Establishing that similar biomechanical adaptations can be achieved via the core stability and balance training protocol compared to the “gold standard” neuromuscular model, would provide a platform for establishing shorter and more compliant training programs in the future. It may also provide a way to integrate injury prevention into the current sports training models that focus on improved performance, as core stability training has become an essential part of these programs.

SPECIFIC AIM 4:

To identify and then compare the relation between training-induced changes in explicit lower limb neuromuscular control strategies and joint biomechanics elicited during unilateral landings following isolated core stability/balance, plyometric, standard neuromuscular and no training programs. Specifically, this study aimed to examine the extent to which core stability/balance and plyometric training, when used as single training modalities, produced adaptations of neuromuscular control strategies that were associated with a concomitant reduction in high-risk lower limb landing biomechanics. To test this aim, both lower limb muscle activation and biomechanical data were quantified and evaluated during a series of unilateral landings prior to and immediately following the respective injury prevention protocols.

Hypotheses:

There is a significant association between training-induced changes of explicit lower-limb neuromuscular control strategies and lower-risk landing biomechanics for all athletes completing an injury prevention protocol (core stability and balance, plyometric and standard neuromuscular).

Subhypothesis 1: For all training (core stability and balance, plyometric and standard neuromuscular), but not the no training group, higher levels of hamstring activation and hamstring to quadriceps co-contraction ratio significantly predict higher peak stance hip and knee flexion angle, and lower peak stance hip and knee moment and anterior knee joint reaction force following training.

Subhypothesis 2: For only the plyometric and standard neuromuscular groups, decreased levels of vastus lateralis, and increased lateral hamstrings activation and lateral hamstring to vastus lateralis co-contraction ratio predict a concomitant reduction in peak stance knee abduction angle and moment following training compared to the no training and core stability/balance groups.

Subhypothesis 3: For both the core stability/balance and standard neuromuscular groups, increased levels of gluteus medius activation significantly predict a reduction in peak stance hip adduction angle and moment following training compared to the control and plyometric groups.

Significance: Determining if the core stability and balance protocol can produce adaptations of neuromuscular control strategies that are linked to modifications in joint biomechanical outcomes similar to those of the “gold standard”, neuromuscular training, may establish a shorter training program that successfully corresponds with a reduction in high-risk lower limb joint biomechanics. It may also provide an avenue to increase compliance within future injury prevention models.

CHAPTER 2

Quadriceps activation patterns predict sagittal plane knee kinetics during single-leg jump landings.

ABSTRACT

Anterior cruciate ligament injury prevention programs purportedly improve knee joint loading through beneficial modification of both lower limb neuromuscular control strategies and joint biomechanics. Current experimental evidence suggests a significant association is evident between neuromuscular control strategies and knee joint biomechanics, however, little is known about which preparatory neuromuscular parameters predict high-risk knee joint biomechanics during single-legged landings. The purpose of this paper was to examine the relation between explicit preparatory lower limb muscular activation patterns and knee joint biomechanics elicited during a single-leg land and cut maneuver. Thirty female athletes had 3D knee joint biomechanics and lower limb EMG data recorded during a series of single-leg jump landings. Stepwise regression analysis was used to assess which muscle activation patterns significantly predicted peak stance knee kinematic and kinetic outcomes suggested to impact the risk of ACL injury. Specifically, pre-activity of VL, LH and RF was submitted to the regression analysis to assess their relation with peak knee flexion angle and moment, as well as, anterior knee joint reaction force, while the pre-activity of VL, LH and MH was inputted to assess their relation with the knee abduction angle and moment. Pre-activity of the rectus femoris predicted peak anterior knee joint reaction force ($R^2 = 0.266$, $b = 1.851$ and $P = 0.004$), while peak stance phase knee flexion moment was explained by pre-activity of both the vastus lateralis and rectus femoris ($R^2 = 0.273$, $b\mathrm{VL} = 0.153$, $b\mathrm{RF} = -0.525$ and $P = 0.013$). Greater rectus femoris activation predicted larger peak anterior knee joint reaction force and decreased knee flexion torque, while larger vastus lateralis activation accounted for greater knee flexion moment during the jump landings, respectively. No preparatory EMG activation parameters were identified as significant predictors ($P > 0.05$) for peak stance knee flexion angle, or knee abduction angle and moment. In conclusion, the current outcomes may highlight the need for reduced quadriceps activation during single-legged landings; however, further research is warranted on the potential benefits of rectus femoris activation. Future injury prevention efforts should focus on reducing reliance on quadriceps activation to provide adequate knee stability during dynamic movements.

INTRODUCTION

Developing lower limb neuromechanical profiles that limit non-contact anterior cruciate ligament (ACL) injury is paramount, as the short and long-term disability of this traumatic injury has been well documented.[81] An ACL injury occurs when excessive tension is applied to the ligament and may result with or without contact from an external object. During a non-contact ACL injury episode, which account for up to 80 percent of all ACL injuries[29, 66, 144], the excessive tension typically occurs during rapid deceleration followed by landing and/or pivoting[17] where a person, him or herself, generates the forces and/or moments at the knee.[244] This injurious ACL loading pattern is thought to stem from high-risk lower limb landing neuromechanics, or rather ineffective neuromuscular control strategies that lead to high-risk joint biomechanics (i.e. joint kinematics and moments).[209] In fact, experimental evidence suggests that the non-contact ACL injury scenario most likely occurs from landing on a single-leg, while the knee is at or near full extension with excessive quadriceps and reduced hamstring muscle activations.[29, 111, 114, 167, 209]

Recent experimental evidence suggests a significant association is evident between neuromuscular control strategies and knee joint biomechanics.[172, 173, 204] Specifically, quadriceps activation and co-contraction of the quadriceps and hamstrings have been associated with knee abduction motion and moments, respectively. During a single-legged forward hop, Palmieri-Smith purported increased preparatory vastus medialis activity predicted decreased knee abduction motion[173], while reactive co-contraction of the vastus medialis and medial hamstring accounted for a significant portion of peak knee abduction moment.[172] Additionally, vastus lateralis activity during the deceleration phase of two-legged stop jump has been identified as a significant predictor of anterior knee joint reaction force.[204] The initial experimental evidence suggests neuromuscular control strategies and knee joint biomechanics are associated. It is unclear, however, how preparatory quadriceps and hamstring activation relate to knee joint kinematics and kinetics.

Neuromuscular control is responsible for maintaining dynamic joint stability, with both preparatory and reactive activation patterns helping to regulate muscle stiffness.[82] A non-contact ACL injury appears to occur from 17 to 50 ms after initial ground contact during landing[114], suggesting there is insufficient time for mechanosensory feedback (i.e. reflex coordinated muscle activity) to provide joint stability and protection against injury. This may indicate that preparatory muscle activation might be necessary for dynamic joint stability.[62, 230] Thus, understanding which preparatory neuromuscular parameters (i.e. specific muscle groups) are related to known high-risk knee joint biomechanical parameters is an important step because it may provide a platform for the current training model to improve program effectiveness and reduce injury risk. The current training model is comprised of an extensive series of specific training modalities, that has known participant compliance limitations.[160] The knowledge of specific neuromuscular parameters to target for a reduction in high-risk lower limb biomechanics may shorten injury prevention protocols, improve effectiveness, and coincide with a reduction in the injury rate. With that in mind, the purpose of this paper is to examine the relationship between explicit preparatory lower limb muscular activation patterns and knee joint biomechanics elicited during a single-leg land and cut maneuver. We hypothesized that higher levels of vastus lateralis activation would be associated with a higher peak stance knee flexion moment, abduction angle and moment, and anterior knee joint reaction force, while higher levels of lateral and medial hamstring activation would be associated with a lower peak stance knee flexion moment and anterior knee joint reaction force, as well as, higher knee flexion angle.

METHODS

Subjects:

A power analysis of our preliminary data indicated 26 subjects per group were needed to achieve 80% statistical power when comparing sagittal knee kinetics with three thigh muscle activity predictors. Thus, thirty female athletes (14.7 ± 0.6 years, 1.64 ± 0.05 m and 55.9 ± 8.7 kg) currently participating on school or club athletic teams involved in high-risk activities (e.g. basketball, field hockey, soccer, and volleyball) were recruited for participation to ensure adequate sample size. Subjects were excluded if they had: (1) a history of previous knee injury or surgery, (2) pain in the lower extremity prior to testing or training, (3) any recent injury to the lower extremity (previous 6 months), and/or (4) currently pregnant. Prior to testing, the University Institutional Review Board granted research approval and written consent was obtained from all participants. Before testing, all subjects had leg dominance assessed and defined as the leg which they could kick a ball the furthest.[138] During data collections, all subjects wore spandex tights and their own athletic shoes.

Neuromechanical Testing

Subjects had synchronous bilateral three dimensional (3D) lower limb (hip, knee and ankle) joint kinetic, kinematic, and surface electromyography data recorded during a series of single-leg jump landings. Two force platforms (AMTI OR6, Advanced Mechanical Technology Inc., Watertown, MA) embedded in the floor captured ground reaction force data, while eight high-speed (240 fps) optical cameras (MX-13, Vicon, Lake Forest, CA) recorded synchronous lower limb motion data during all jump landings. For all landings, the subjects jumped from a distance equal to the length of their dominant limb from the front edge of the force platforms and over a 17 cm box.

The single-leg jump-landing task required subjects to perform one of two (L1 or L2) pre-defined, randomly ordered landings.[31, 34] For L1, subjects jumped forward, landed only on their left foot and then aggressively jumped laterally to the right, while for L2, subjects jumped forward, landed on their right foot and immediately jumped laterally to the left (Figure 2.1). To successfully complete the landing protocol, subjects were required to perform five successful single-leg landings of each of the two conditions.

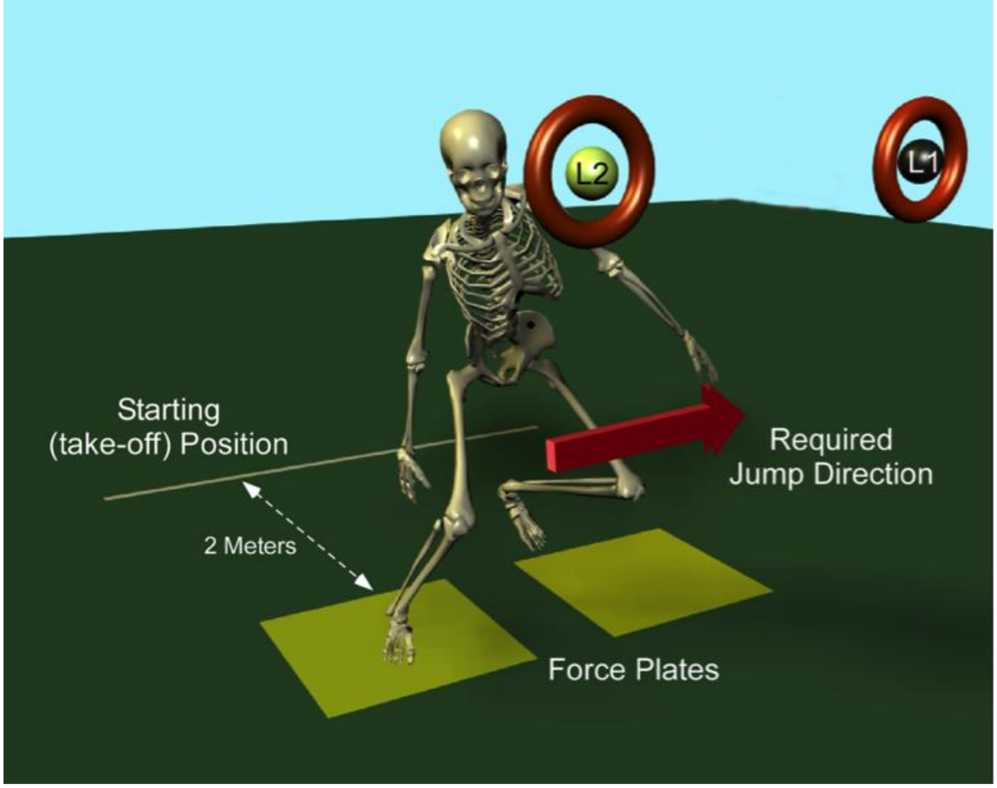


Figure 2.1 Subjects reacted to a random light stimulus and move in the appropriate direction upon landing from a forward jump. Two lights were used, corresponding to a rapid land and jump to the right (L1) or left (L2). * Adapted from Borotikar et al., (2008). *Clin. Biomech.*

Biomechanical Analyses

For each landing trial, lower extremity joint rotations were quantified based on the 3D coordinates of thirty-one (14 mm diameter) precisely attached reflective skin markers (Figure 2.2).[31] The markers were attached and secured to pre-determined anatomical landmarks via double-sided tape and hypoallergenic, air-permeable cross elastic tape (Cover-Roll Stretch, BSN medical GmbH, Hamburg, Germany) by a single experimenter (TNB). Attachment over areas of large muscle/tissue mass was avoided to prevent excessive marker movement during ground contact.

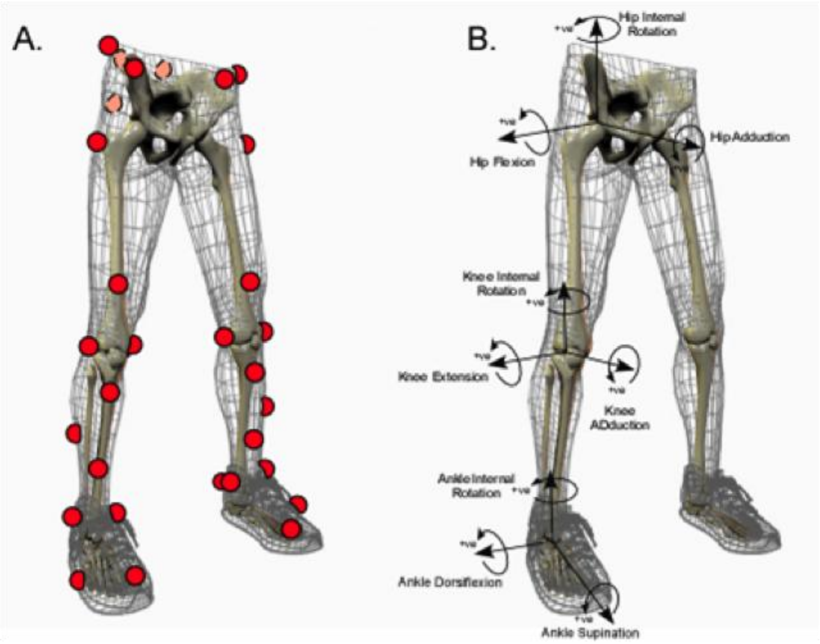


Figure 2.2 Marker set for movement analysis (**A**) and model for skeleton kinematics and kinetics (**B**) of the right (contact) leg.* Adapted from Borotikar et al., (2008). *Clin. Biomech.*

Following marker placement, a high-speed video recording of the subject standing in a stationary (neutral) position was taken. From the stationary recording, a kinematic model comprised of seven skeletal segments (bilateral foot, shank and thigh segments and the pelvis) with 24 degrees of freedom was defined using Visual 3D v3.99 software (C-Motion, Rockville, MD). The pelvis was defined with respect to the global (laboratory) coordinate system and assigned six (three translational and three rotational) degrees of freedom.[138, 139, 242] Hip[20], knee[83, 228], and ankle[242] joint centers and associated orthogonal local segment (3 degrees of freedom) coordinate systems were defined in accordance with previous literature and our own previous work.[20, 83, 228, 242]

Synchronous 3D ground reaction force (GRF) data were collected at 1200 Hz during each jump landing and along with the 3D marker trajectories, low pass filtered with a fourth-order Butterworth filter at a cut-off frequency of 12 Hz.[34, 142] The 3D marker trajectories recorded during each jump landing trial were subsequently processed by the Visual 3D software to solve for the lower limb joint rotations at each time frame. Resultant hip and knee joint rotations were expressed relative to the subject's static (neutral) 3D posture.[110, 134, 138, 173] The filtered kinematic and GRF data were processed using conventional inverse dynamics analyses to obtain 3D intersegmental forces and moments at each lower limb joint.[235] The segmental inertial properties were defined in accordance with the work of Dempster.[57] Hip and knee 3D intersegmental forces were transformed to respective distal segment reference frames (femoral and tibial) and anterior-posterior, medial-lateral and compression-distraction forces were calculated. The resultant intersegmental moments at the hip and knee were characterized as flexion-extension, abduction-adduction and internal-external rotation moments with respect to the cardanic axes of their respective joint coordinate systems.[138, 139] All joint moments were normalized to participant body mass (kg) and height (m), while force values were normalized to body mass. The kinematic and kinetic data were time-normalized to 100% of stance (heel strike to toe-off) and re-sampled at 1% increments (N = 101) with heel strike and toe-off defined as the instant GRF first fell below and exceeded 10 N, respectively [31].

Electromyography Analysis

During all jump-landing trials, subjects had lower extremity muscle activity quantified with surface electromyography (EMG) electrodes. Electromyographic data were recorded at 1200 hertz using a 16 channel EMG system (Delsys, Boston, MA), synchronized with the force platforms via a motion capture system (MX-13, Vicon, Lake Forest, CA). Surface EMG electrodes (DE-2.1), with 10 mm inter-electrode distance recorded the lower extremity muscle activity. The EMG electrodes were placed over the muscle bellies of the medial (MH) and lateral hamstrings (LH), vastus lateralis (VL), and rectus femoris (RF) muscles according to the guidelines of Delagi[54] during all landings. The electrodes were attached to the skin using hypoallergenic, air-permeable cross elastic tape (Cover-Roll Stretch, BSN medical GmbH, Hamburg, Germany) and covered with spandex shorts or cohesive athletic tape (Powerflex, Andover Healthcare, Inc., Salisbury, MA). Prior to collection of the landing trials, EMG data was recorded during a two-second maximal voluntary isometric contraction (MVIC) for both the quadriceps and hamstrings. During all MVICs, subjects were seated with their hip and knee angle approximately 90° and 45°, respectively, and were instructed to perform a maximal extension or flexion contraction into the resistance of the examiner.

Both the dynamic and MVIC EMG data were band-pass (10 – 500 Hz) filtered with a fourth order, zero lag Butterworth filter to attenuate movement artifacts and processed with a 50-millisecond root mean square (RMS) moving window. The dynamic EMG data was normalized to the MVIC activity of the respective muscle before calculating average RMS activity during the pre-activity (100 ms prior to ground contact) phase.

Statistical Analysis:

Multiple stepwise regressions were fit using SPSS (18.0, SPSS Inc., Chicago, IL) to determine which muscle activation patterns significantly predicted peak stance kinematic and kinetic outcomes suggested to impact the risk of ACL injury.[69, 93, 109, 138] Activation variables analyzed included average RMS activity of the LH, MH, VL and RF muscles during the pre-activity phase. The biomechanical response variables identified were peak knee flexion and abduction angles and moments, as well as, peak anterior knee joint reaction force. The kinematic and kinetic variables, however, were only considered between 0% and 50% of stance phase, as ACL injury is suggested to occur within this time frame.[81, 105] Pre-activity of VL, LH and RF were submitted to a regression analysis to assess their relation with peak knee flexion angle and moment, as well as, anterior knee joint reaction force, while the pre-activity of VL, LH and MH were inputted to assess their relation with the knee abduction angle and moment. An alpha level of 0.05 was selected to determine if predictor variables would be included in the final equation and for determining the significance of the model in predicting the response variable.

RESULTS

Means and standard deviations for the pre-activity phase EMG parameters are presented in Table 1. Figure 2.3 depicts peak stance (0 – 50 %) phase knee joint biomechanical data elicited during the single-legged landing task. During the single-leg landing maneuver, mean peak stance phase knee flexion and abduction angles were -60.00 ± 8.40° and -3.43 ± 2.41°, respectively, while peak stance knee flexion and abduction moment means were 1.53 ± 0.26 N/kg/m and 0.39 ± 0.14 N/kg/m. Finally, the mean peak normalized anterior knee joint reaction force during the single-legged maneuver was 0.29 ± 0.75 N/kg of BM.

Table 2.1: Average RMS activation (mean ± SD) of the dominant limb for the pre-activity phase of the single-legged landing maneuver.

Variable	**Pre-activity (% of MVIC)**
Vastus Lateralis (VL)	133.4 ± 59.6
Rectus Femoris (RF)	46.1 ± 20.7
Lateral Hamstring (LH)	43.7 ± 28.7
Medial Hamstring (MH)	45.9 ± 22.8

Partial coefficients from the full linear regression models evaluating the association of pre-activity EMG variables with anterior knee joint reaction force and flexion moment are presented in Table 2. Pre-activity of the rectus femoris was found to be a significant predictor of peak anterior knee joint reaction force ($R^2 = 0.266$, $b = 1.851$ and $P = 0.004$) (Figure 2.4). Specifically, a 10% increase in preparatory rectus femoris activation (% of MVIC) predicted a 0.18 N/kg increase in anterior reaction force, when holding the other predictors constant. A significant portion of the variance in peak stance phase knee flexion moment was explained by pre-activity of the vastus lateralis and rectus femoris ($R^2 = 0.273$, $b\text{VL} = 0.153$, $b\text{RF} = -0.525$ and $P = 0.013$). Specifically, when holding other predictors constant a 10% increase in vastus lateralis pre-activity (% of MVIC) predicted a 0.02 N/kg/m increase in knee flexion moment, while a 10% increase in preparatory rectus femoris activation (% of MVIC) was associated with a 0.05 N/kg/m decrease in knee flexion moment (Figure 2.4). No preparatory EMG activation parameters were identified as significant predictors ($P > 0.05$) for peak stance knee flexion angle, or knee abduction angle and moment.

Table 2.2: Regression coefficients from the full stepwise regression models associating pre-activity muscle activation variables with key peak stance (0%–50%) phase knee joint biomechanical parameters.

Variable	**Anterior Reaction Force**			**Flexion Moment**		
	β	**t**	**P**	**β**	**t**	**P**
VL	-0.142	-0.870	0.392	0.153	2.116	0.044*
RF	1.851	3.186	0.004*	-0.525	-2.538	0.017*
LH	0.167	1.018	0.318	-0.169	-1.991	0.326

* Denotes partial regression coefficient is statistically significant.

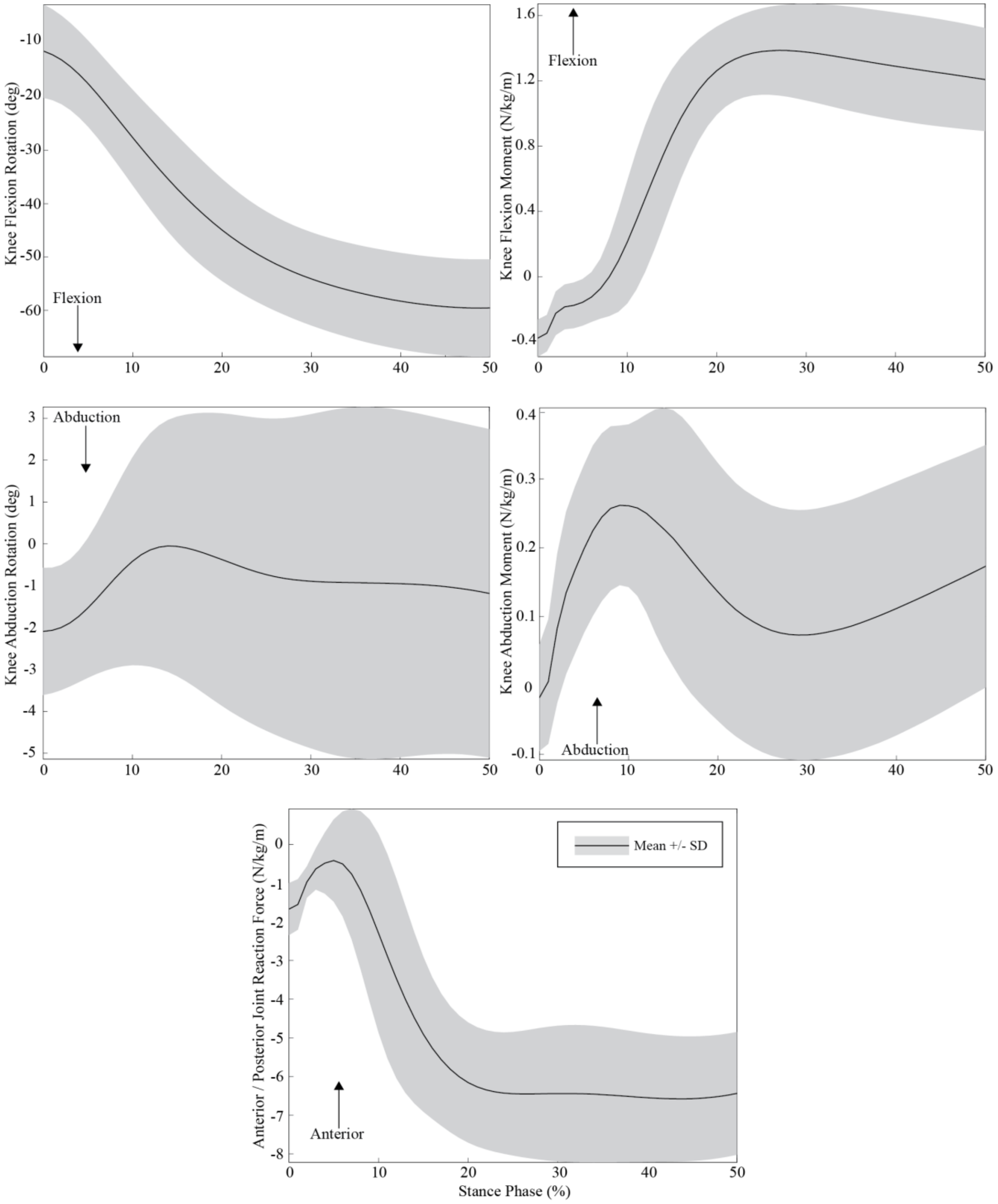


Figure 2.3 Mean (± SD) stance phase knee biomechanical patterns during the single-legged landing maneuver. Stance phase patterns for knee anterior joint reaction force, abduction angle and moment, and flexion angle and moment are presented.

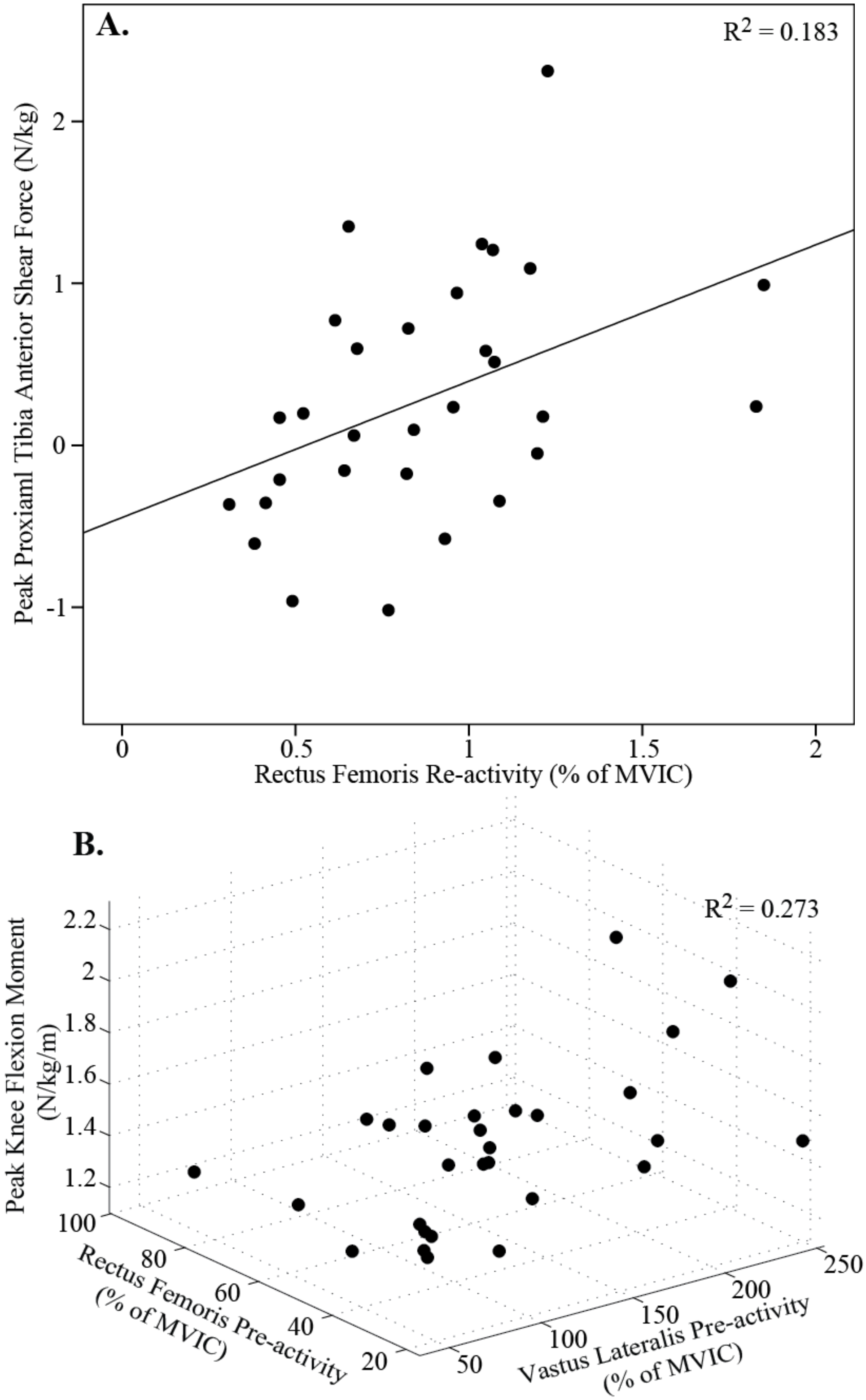


Figure 2.4 Relation between peak proximal tibia anterior shear force and rectus femoris pre-activity (**A**), and peak stance knee flexion moment with recuts femoris and vastus lateralis pre-activity (**B**) during single-legged landings.

DISCUSSION

Recent experimental evidence has identified a significant association between lower limb neuromuscular control strategies and joint biomechanics.[172, 173, 204] A non-contact ACL injury scenario may stem from ineffective neuromuscular control strategies that precipitate specific high-risk joint biomechanics during landing and/or pivoting maneuvers.[209] Thus, it may be of upmost importance to identify these specific muscle activation strategies that predict high-risk knee joint biomechanics. With that in mind, the purpose of this paper was to examine the relationship between explicit preparatory lower limb neuromuscular control strategies and knee joint biomechanics elicited during a single-leg land and cut maneuver.

Outcomes of the current study suggest that greater pre-activity of the rectus femoris predicted increased peak anterior knee joint reaction force during the single-leg land and cut maneuver. These findings are consistent with previous biomechanical modeling[183, 207] and cadaveric data of the knee joint[118, 237], and suggest greater preparatory rectus femoris activation may coincide with greater ACL load. The ACL acts as the major restraint of anterior displacement of the tibia on the femur[24, 36, 128] and carries nearly all the anteriorly directed force at the knee joint.[185, 186] Consequently, anterior knee joint reaction force may be an indicator of ACL load[199, 204, 244] and subsequent injury risk. The current outcomes suggest that excessive quadriceps contraction, specifically preparatory rectus femoris activation, during a single-leg jump landing is linked to anterior knee joint reaction force and may increase the risk of ACL injury. Therefore, injury prevention programs may be warranted to focus on developing neuromechanical strategies that target the reduction of rectus femoris activitation, as a means to decrease injury risk.

Interestingly, a significant relation between hamstrings activation with peak anterior knee joint reaction force was not evident during the single-legged landings. Hamstrings contraction has been previously shown to create a posterior shear force at the knee joint.[65, 130, 238] Thus, hamstrings contraction should act to reduce anterior knee joint reaction force magnitudes[183] and improve knee stability. Our current observations, however, do not support the existence of such a relation. The reasons for this discrepancy are not currently known, but recently Bennett et al.[22] found quadriceps and hamstrings strength were not significant predictors of peak anterior tibial shear force, as well. The authors concluded that anterior shear may be a function of the available strength at a given point joint angle rather than peak strength. Although, we currently did not measure strength, since there is a high correlation between EMG amplitude and force[152], it may be anterior shear is a function of amplitude at given joint angle rather peak activation. Thus, future work may be warranted to determine if neuromuscular training improves hamstrings activation profiles that strengthen its relation with and opposition to peak anterior knee joint reaction force during single legged landings.

A significant linear relation was also observed between rectus femoris and vastus lateralis activation, and peak stance knee flexion torque. Specifically, greater pre-activity of both the rectus femoris and vastus lateralis predicted peak stance knee flexion moment. Interestingly, increased rectus femoris pre-activity was associated with a reduced knee flexion moment, while greater pre-activity of the vastus lateralis predicted increased flexion torque. The reason for the discrepancy in the relation between the preparatory activity of the two quadriceps muscles and knee flexion torque is unknown. It may be the greater pre-activity of the rectus femoris, a bi-articular muscle crossing both the hip and knee, increases hip flexion posture. Recently, Shultz et al.[213] demonstrated that greater hip flexion posture during bilateral drop landings is associated with a reduced knee flexion moment. Although this is speculative, as hip posture was not quantified, increased preparatory rectus femoris activation may allow for greater hip flexion during landing, affording the quadriceps improved eccentric control of the knee joint. The increased vastus lateralis activation, however, may be a neuromuscular control strategy preferred by females[192] used to cope with the demands of controlling the center of mass during the single-legged landings. Single-legged landings may require greater eccentric vastus lateralis contraction to increase knee stiffness[77], balance the external knee flexion moment and prevent joint collapse following contact during the landing phase.[146] Those participants currently presenting greater eccentric vastus lateralis activity may have increased injury risk as a result of the elevated activation. The current findings support this contention and highlight the need for future injury prevention efforts to develop neuromuscular profiles that limit quadriceps activation as it may precipitate increased ACL injury risk.[56]

The current outcomes suggest that limiting excessive quadriceps activation may reduce ACL injury risk. A means for injury prevention modalities to target reduced reliance on quadriceps activation during jump landings would be to focus on increasing quadriceps strength. Lower limb strength has been shown to be a moderate predictor of preparatory activation levels during dynamic landings[213] and thus weaker athletes may rely upon greater quadriceps activation to promote adequate knee stability. Thus, the fact that greater activity of the vastus lateralis was associated with increased knee flexion moment suggests improved quadriceps strength may reduce sagittal plane knee joint loading during jump landings. This increased quadriceps strength may also afford the participant an improved knee flexion profile that allows for decreased rectus femoris activation and the subsequent peak anterior knee joint reaction force. Although this is purely speculative, as we did not quantify quadriceps strength, greater strength may allow the athlete to maintain adequate knee stability with lower quadriceps activation levels and possibly decreased ACL loading.

The current findings are in agreement with the previous contention that hamstring activation does not relate to peak stance knee flexion moment.[213] It was previously suggested that lower limb kinematics may be the driving force behind variations in knee flexion moments. Further analysis of previous experimental evidence suggests that lower limb postures, i.e. greater trunk flexion, during landing may predict decreased knee flexion moment and improved hamstring activity.[208, 232] Thus, future work may need to focus on lower limb biomechanical parameters, specifically trunk control, that are associated with a reduced knee flexion moment to provide future injury prevention modalities a platform for reduce sagittal plane injury risk.

The current regression model suggested that there was no significant association between any lower limb muscle activation pattern and knee flexion posture. Interestingly, these findings are in agreement with previous work examining the association between preparatory thigh muscle activation, and hip and knee biomechanics during a bilateral drop landing.[213] It may be that activation of the thigh musculature plays a larger role in providing dynamic knee stability, i.e. proper coordination of activation patterns to provide adequate muscle stiffness around the joint, than a significant role in controlling specific sagittal plane knee kinematics during the landing phase of single-leg land and cut maneuvers. It may be that sagittal plane knee kinematics are driven by the joint excursions up and down the kinetic chain, rather than by specific muscle activity patterns. Specifically, it may be that the posture of both the hip[213] and ankle[208] influence sagittal plane knee biomechanics, while the musculature that crosses the knee act to aid with joint stability, but do not cause and/or prevent injurious ACL loading.[92] This is purely speculative, but warrants further investigation.

Outcomes of the current study identified no significant preparatory quadriceps or hamstring activation parameters as predictors of knee abduction angle or moment. Despite the fact, the quadriceps and hamstring muscles have moment arms that support frontal plane moments[121, 250], can resist knee valgus laxity and knee abduction[250] and may be the most potent knee stabilizer.[122] These results also contradict previous experimental evidence, which suggested the increased pre-activity of the lateral thigh musculature was significantly associated with knee abduction motion.[173] The reason for this contradiction is unknown, however, it may stem from differences between landing tasks and subject population. Palmieri-Smith et al.[173] recruited recreationally active individuals to perform a dominant limb forward hop, while we analyzed competitive athletes performing a single-leg land and cut maneuver. Competitive athletes may possess refined neuromuscular control strategies [214] and use a more consistent movement strategy during the execution of complex movements[103, 141, 214], which may help account for the current discrepancies. Besier et al.[26], however, demonstrated that competitive males athletes used pre-planned activation patterns that were selected to support and potentially resist external valgus loads experienced at the knee during an single leg side-step maneuver. This discrepancy may stem from sex differences in neuromuscular control strategies. Female athletes have been shown to use greater quadriceps[85, 125, 162, 213] and reduced hamstring activation[43, 125] compared to males. They also demonstrate greater medial to lateral thigh muscle activation imbalance[172], which has been associated with greater valgus posture.[173] Regardless, limiting knee abduction may essential to reducing ACL injury risk because it has been prospectively linked to injury risk[95] and when combined anterior translational of the tibia produces the largest amount of ACL strain.[24] Future research is warranted to determine if it is specific task, subject or performance training differences that result in the discrepancy between the current and previous evidence regarding neuromuscular strategies that govern knee abduction posture and loading. An understanding of specific activation patterns to target in competitive female athletes that reduce hazardous knee abduction motion and loading may coincide with a reduction in non-contact ACL injury rate.

CONCLUSION

In conclusion, preparatory quadriceps activation patterns were associated with high-risk knee joint biomechanics during a single-leg land and cut maneuver. Specifically, greater rectus femoris activation predicted larger peak anterior knee joint reaction force and decreased knee flexion torque, while vastus lateralis activation accounted for greater knee flexion moment during the jump landings, respectively. The current outcomes highlight the need for reduced quadriceps activation during single-legged landings; however, further work is needed to understand the potential impact of rectus femoris activation on knee biomechanics. Future injury prevention efforts should focus on reducing reliance on quadriceps activation to provide adequate knee stability during dynamic movements. Future research is also warranted to find explicit neuromuscular control strategies to target for reduced knee abduction motion and loading.

CHAPTER 3

Comparative training-induced lower limb joint biomechanical adaptations between uni-lateral and bi-lateral landings

ABSTRACT

Current ACL injury prevention efforts elicit modification of high-risk lower limb biomechanics during bilateral landings. It is unknown whether the same training adaptations are transitioned to unilateral landings following neuromuscular training. The purpose of this study was to compare key lower-limb biomechanical adaptations between bilateral and unilateral jump landings arising via a comprehensive neuromuscular training program. Twenty trained and thirteen control participants were included in the final analysis. Knee and hip three-dimensional kinematic data were analyzed during a series of uni- and bi-lateral jump landings immediately prior to and following a six-week neuromuscular training program. Subject-based mean values of sagittal and frontal plane kinematics were submitted to three-way repeated measures ANOVAs to test for the main and interaction effects of training group, movement type and testing session. A significant three-way interaction was exhibited for peak stance knee flexion ($p = 0.039$), with significantly greater knee flexion during the bilateral landings for the training group post-training ($p = 0.002$) than the controls. Significantly greater peak stance knee flexion ($p = 0.033$) was evident pre- when compared to the post-training time point. Females

displayed significantly greater initial contact and peak stance hip ($p < 0.001$) and knee ($p< 0.001$) flexion, and hip adduction ($p < 0.001$), as well as, peak stance knee abduction ($p < 0.001$) postures for bilateral landings when compared to the unilateral landings. These results indicated current neuromuscular-based ACL injury prevention methods that achieve lower risk lower limb bilateral landing biomechanics may not produce similar benefits during unilateral landings. Injury prevention programs that improve both uni- and bi-lateral landing biomechanics may more effectively reduce the non-contact ACL injury rate.

INTRODUCTION

Anterior cruciate ligament (ACL) injury is a common and traumatic sports related injury, carrying significant short and long-term morbidity, particularly in females.[81] The typical ACL injury occurs during rapid deceleration and/or pivoting maneuvers[167], where high-risk three-dimensional knee joint biomechanical states are proposed to arise via ineffective overarching neuromuscular control strategies. Landing extended and/or with increased frontal plane hip and knee postures, can culminate in excessive anterior tibial shear loading and/or knee abductions loads, which are considered particularly hazardous biomechanical outcomes during dynamic sports movements.[172, 245] Establishing interventions that can minimize these purported high-risk knee joint biomechanical profiles thus appears paramount to decreasing the non-contact ACL injury rate.

Current neuromuscular-based ACL injury prevention methods have shown promise in being able to counter high-risk lower limb joint biomechanics during specific landing maneuvers.[158] These injury prevention programs are typically based on the rationale that "lower-risk" landing mechanics[95] during sporting activities can be achieved through successful modification of explicit hip and knee postures[158] and loads[44] elicited during bilateral (stop jump or drop vertical jump) landings.[44, 158] In spite of these continued efforts and reported early successes[95], however, ACL injury rates have endured.[2] One key reason for this shortcoming may be that training program "success" has been defined via a limited focus on the bilateral landing task, which may not truly reflect the sports-relevant landing maneuvers during which ACL injury commonly occurs.[81] Currently, little is known regarding whether trained neuromechanical adaptations are possible for unilateral landings[157], despite the fact most ACL injuries occur during such tasks.[167] Experimental evidence suggests significant and potentially important differences exist in lower extremity landing biomechanics between uni- and bi-lateral landings. Unilateral landings, for example, present with noticeably different sagittal and frontal hip and knee biomechanical profiles compared to bilateral landings.[63, 163, 176] Basing the success of ACL injury prevention methods on the ability to modify lower limb biomechanics during isolated bilateral landings may thus be problematic.

To date, no one has compared the biomechanical adaptations between uni- and bi-lateral landings following a standard neuromuscular-based ACL injury prevention protocol. Determining if trained biomechanical adaptations during bilateral landings are similarly evident for unilateral landings, which more closely represent a non-contact ACL injury movement scenario, may be an important step in more effectively reducing injury rates. With this in mind, the purpose of the current study was to compare key lower-limb biomechanical adaptations between bilateral and unilateral jump landings arising via a comprehensive neuromuscular training program. We hypothesized that following a six-week neuromuscular training program, participants would demonstrate significantly greater increases in initial contact and peak stance hip and knee flexion angles, and significantly greater decreases in peak stance hip adduction and knee abduction angles during bilateral compared to the unilateral landings.

METHODS

Subjects:

An *a priori* power analysis indicated 13 subjects per group were needed to achieve 80% statistical power based on recent data comparing sagittal and frontal plane hip and knee kinematics of ACL injured and uninjured female athletes.[98] Previous research also suggested that an 80% subject completion rate of the training program was to be expected.[158] We thus anticipated that recruiting 18 women for the training group and 16 women for the control would be sufficient. We collected a larger number of (29 train and 20 control) subjects, however, to ensure adequate sample size. Less control participants were recruited, as similar noncompliance issues to the training group were not anticipated.

The final analysis included thirty-three (20 train and 13 control) subjects (Table 3.1) as subject attrition was greater than expected for both the control and training participants. Excluded subjects did not complete adequate amount of training and/or testing to be included in the final analyses. Successful completion of the training program required the subject to participate in at least 16 of the 18 possible training sessions. All subjects were females between the ages of 15 and 22, and recreationally active, based on them exercising at least two times per week and having a rating of 5 or higher on the Tegner scale.[225] Subjects were excluded if they: (1) had a history of previous knee injury or surgery, (2) had pain in lower extremity prior to testing or training, (3) had any recent injury to the lower extremity (previous 6 months), and/or (4) were currently pregnant. Prior to testing, research approval was received through our Institutional Review Board and written informed consent was gathered from all participants. Prior to data collection leg dominance was assessed, with the dominant leg defined as that which could kick a ball the furthest.[34] All subjects were identified as right leg dominant. During testing, all subjects wore spandex tights and their own athletic shoes.

Table 3.1. Subject Characteristics

	Train (n = 20)	**Control (n = 13)**	**p-value**
Age	19.2 ± 1.3 years	18.7 ± 2.1 years	0.37
Height	1.63 ± 0.06 m	1.67 ± 0.07 m	0.22
Weight	59.6 ± 7.2 kg	58.7 ± 9.6 kg	0.77

Experimental Design:

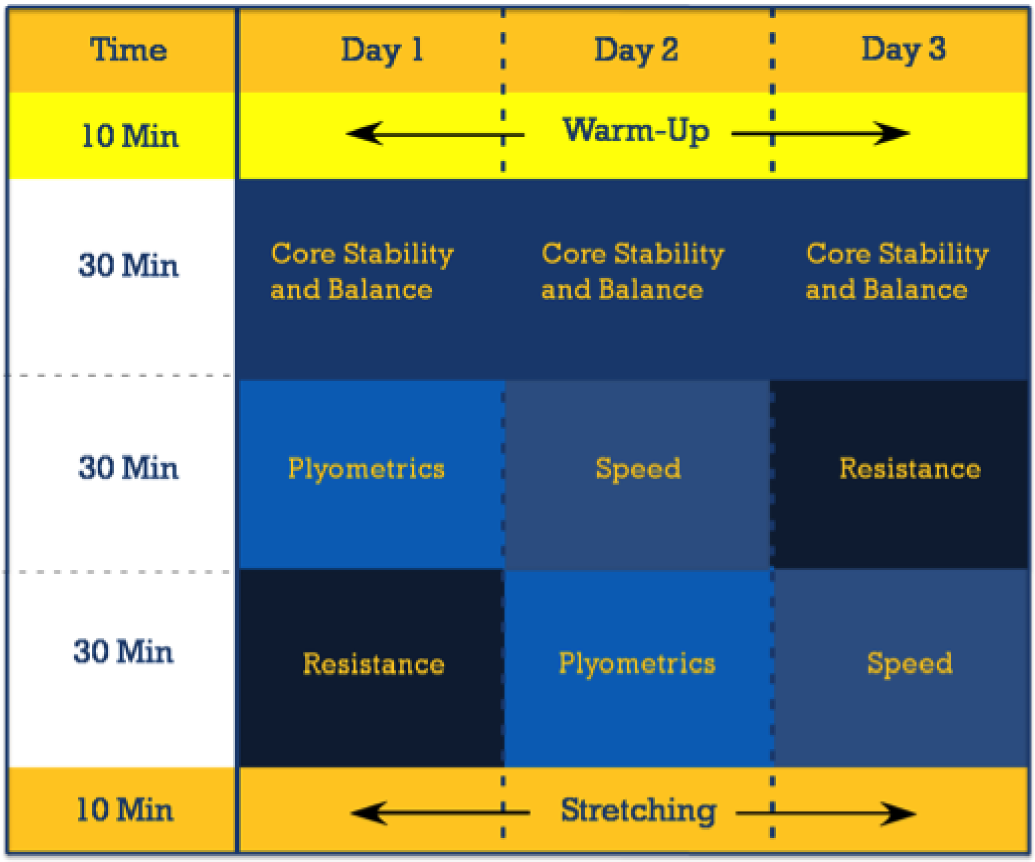
A randomized pre-test post-test study design was used to test the key hypotheses. All subjects were required to complete two testing sessions. Eligible participants were randomly allocated into one of two groups, training and control, following the first (baseline) testing session at a ratio of 3 training to every 2 control participants. The second testing session occurred immediately following (within two days) a six-week training program (training group), or after a similar six-week break (control group).

Neuromuscular Training:

The training group participants received three 90-minute neuromuscular training sessions per week over the six-week training period, for a total of 18 sessions. Participants randomized to the control group were untrained and asked to continue their normal daily activities during the six-week period between testing sessions.

The neuromuscular training program included the following components: core strength and balance, plyometrics, resistance, and speed training, which were derived from previous prevention techniques touted to be effective at reducing the biomechanical measures associated with ACL injury.[95, 158] Each 90 minute training session was composed of three specific 30-minute components. Subjects were also asked to perform an active warm-up before and stretching cool down after each session for 10 minutes, respectively. The core strength and balance training was performed first in every session because these exercises have been advocated in prevention of lower extremity injuries[157], and lack of core conditioning may lead to faulty landing mechanics. The remaining components (plyometrics, resistance, and speed training) were varied systematically across days to limit disinterest and/or fatigue of components occurring later in the session.[158] The training schedule, however, was consistent between weeks and subjects (Figure 3.1).

The early sessions of the six-week neuromuscular training program were used to develop correct dynamic movement technique (e.g. deep bending of the knees upon landing and proper alignment of the knees over the balls of their feet and chest over their knees).[95] At all times during training, at least three individuals skilled in the identification of proper technique for a given exercise provided constant encouragement and feedback (visual and verbal) to establish correct form.[95] After establishing proper technique during the initial sessions (Phase 1), the training protocol progressively increased intensity of the exercises to develop safe, powerful and efficient dynamic movement patterns (Phases 2 and 3). Each of the four (core strength and balance, plyometrics, resistance and speed) training components had sub-goals that contributed to the overall goal of the training program, which was to improve dynamic knee joint loading. Exercises of the specific neuromuscular training program are presented in detail in Appendix A.



Time	Day 1	Day 2	Day 3
10 Min	← Warm-Up →		
30 Min	Core Stability and Balance	Core Stability and Balance	Core Stability and Balance
30 Min	Plyometrics	Speed	Resistance
30 Min	Resistance	Plyometrics	Speed
10 Min	← Stretching →		

Figure 3.1 The weekly schedule for the six-week neuromuscular training program consisting of exercises from four components (core strength and balance, plyometrics, resistance and speed).

Biomechanical Procedures:

Subjects had three-dimensional (3D) lower limb (hip and knee) joint kinematics quantified for uni- and bi-lateral jump landings, both pre and post training. A successful trial in each instance required subjects to land on a force platform (AMTI OR6-7, Advanced Mechanical Technology Inc., Watertown, MA) embedded in the floor, within the view of eight high-speed (240 fps) optical cameras (MX-13, Vicon, Lake Forest, CA). For all jump landings, subjects initiated take-off one meter behind the force platform and jumped over a 17 cm box prior to landing.[34] The unilateral landing task required subjects to perform one of two pre-defined, randomly ordered landings [31, 34] where they initiated a two-legged take off and either landed on their left foot and then aggressively jumped laterally to the right or they landed on their right foot and immediately jump laterally to the left (Figure 2.1). Subjects were required to successfully complete four single-leg landings off both the dominant and non-dominant limbs. For the double-leg landing task, subjects jumped forward and immediately performed a maximal vertical jump off both limbs upon landing. Subjects were required to successfully perform four double-legged landings. Maximal vertical jump height following the landing was calculated based on the time in air, using a uniform acceleration equation shown to have good intersession reliability.[150]

For each landing trial, lower extremity joint kinematics were quantified based on the 3D coordinates of thirty-one (14 mm diameter) precisely attached reflective skin markers (Figure 2.2). The markers were attached and secured to pre-determined anatomical landmarks via double-sided tape and hypoallergenic, air-permeable cross elastic tape (Cover-Roll Stretch, BSN medical GmbH, Hamburg, Germany) by a single experimenter

(TNB). Attachment over areas of large muscle/tissue mass was avoided to prevent excessive marker movement during ground contact. Finally, spandex tights were pulled over the legs and small cuts were made in the material allowing all markers to show through, to further prevent the potential for marker movement or loss during the dynamic landings.[31, 34]

Following marker placement, a high-speed video recording of the subject standing in a stationary (neutral) position was taken. A kinematic model comprised of seven skeletal segments (bilateral foot, shank and thigh segments and the pelvis) with 24 degrees of freedom (DOF) was defined using Visual 3D v3.99 software (C-Motion, Rockville, MD) from the stationary recording. The pelvis was defined with respect to the global (laboratory) coordinate system and assigned six (three translational and three rotational) degrees of freedom (DOF).[138, 242] Hip,[19] knee,[83] and ankle[242] joint centers and associated orthogonal local segment (3 DOF) coordinate systems were defined in accordance with previous literature and our own previous work.[31, 34]

The 3D marker trajectories recorded during each jump landing trial were low pass filtered with a fourth-order Butterworth filter at a cut-off frequency of 12 Hz[34] and subsequently processed by the Visual 3D software to solve for the lower limb joint rotations at each time frame. Resultant hip and knee joint rotations were expressed relative to the subject's static (neutral) 3D posture.[138, 173] All kinematic measures were time-normalized to 100% of stance (heel strike to toe-off) and re-sampled at 1% increments (N = 101) with heel strike and toe-off defined as the instant GRF first fell below and exceeded 10 N, respectively.[31]

Statistical Analysis:

Baseline subject characteristics (height, weight, and age) and average vertical jump height were compared between the training and control groups using independent t-tests. Specific kinematic parameters were submitted to pre-planned statistical treatment based on their previously suggested links to ACL injury.[98, 138] Specifically, hip and knee flexion-extension, and abduction-adduction angles at initial contact and peak, between 0% and 50%, of stance were analyzed. Stance phase kinematics were considered over the first 50% only, as ACL injury is suggested to occur within this time frame.[81] Subject-based mean values of each kinematic dependent measure were submitted to a three-way ANOVA to test for the main effects of and possible interactions between group (neuromuscular training versus control), movement type (unilateral and bilateral landings) and testing session (pre and post). In instances where statistically significant differences between sessions were observed, Bonferroni pairwise comparisons were used. Significant three-way interaction effects were submitted to one-way ANOVAs stratified by training group and followed by independent t-tests to test for simple main effects. An alpha level of 0.05 was used to denote significance for each statistical comparison. Cohen’s d was used to calculate effect size by subtracting the control mean from the training mean and dividing by the pooled standard deviation.[50]

RESULTS

There were no statistically significant differences (p > 0.05) in the baseline subject characteristics or pre-training vertical jump height between groups, suggesting successful randomization (Table 3.1 and 3.2). Thus, we interpreted our remaining statistical comparisons with confidence.

Table 3.2. Average Vertical Jump Height

	Train	**Control**	**p-value**
Pre	.23 (.07) m	.24 (.05) m	0.51
Post	.24 (.05) m	.24 (.06) m	0.93

The ANOVA revealed a significant three-way interaction for peak knee flexion (p = 0.039) (Figure 3.2). Post-hoc analyses indicated that peak knee flexion recorded during bilateral landings was significantly larger for the training group at the post-training time point (p = 0.002) compared to the controls. This same difference, however, was not noted for the pre-training time point (p = 0.135, 1 - β = 0.495 and d = 0.56).

A main effect for training group was found for peak stance knee flexion (p = 0.004) (Table 3.3 and 3.4). Specifically, training group participants exhibited significantly greater peak stance knee flexion when compared to the control subjects. No group differences, however, were observed for initial contact hip (p = 0.548, 1 - β = 0.091 and d = 0.22) and knee flexion (p = 0.201, 1 - β = 0.245 and d = -0.48) or hip adduction (p = 0.921, 1 - β = 0.051 and d = 0.04) and knee abduction (p = 0.889, 1 - β = 0.052 and d = 0.04) postures. Furthermore, no significant group differences were evident for peak stance phase hip flexion (p = 0.112, 1 - β = 0.354 and d = 0.60) or adduction (p = 0.458, 1 - β = 0.105 and d = -0.26), and knee abduction (p = 0.990, 1 - β = 0.050 and d = 0.005) postures.

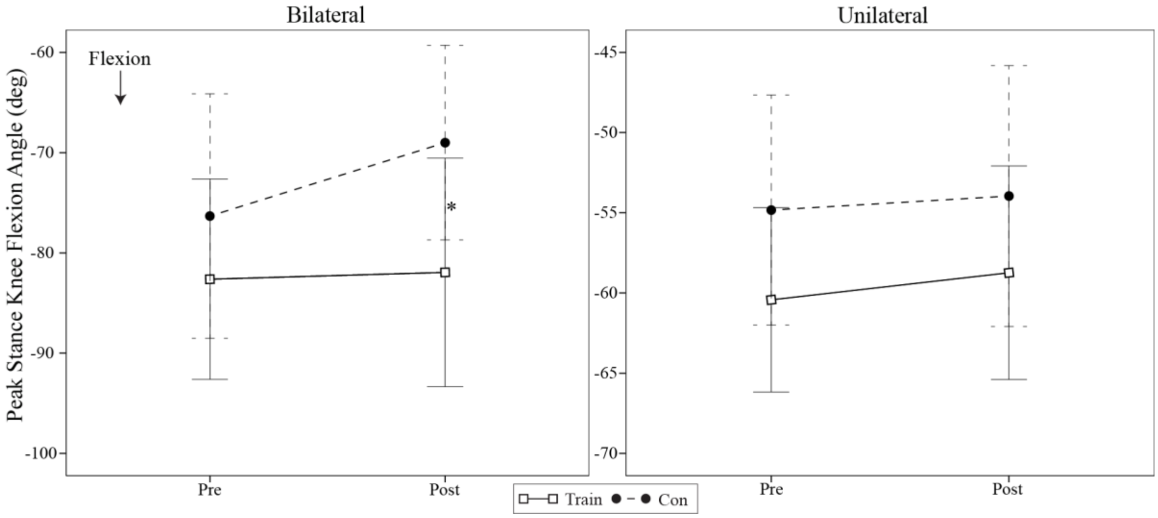


Figure 3.2 A plot comparing the mean Pre and Post peak stance knee flexion posture for both unilateral and bilateral landings between the Trained and Control participants. The neuromuscular training participants produced significantly greater knee flexion during the bilateral landings at the post-training (p = 0.001) but not the pre-training time point (p = 0.135) compared to the controls. * indicates significant difference between group.

Table 3.3. Peak Stance (0% - 50%) Phase Hip and Knee Rotations

		Pre		**Post**	
		Single	**Double**	**Single**	**Double**
Hip Flx*	**Train**	38.9 (7.4)	54.6 (10.0)	42.5 (5.4)	57.0 (10.2)
	Control	37.2 (7.1)	52.8 (9.3)	37.1 (6.8)	51.8 (6.2)
Hip Add*	**Train**	0.8 (5.5)	5.8 (2.6)	0.2 (6.2)	5.1 (3.8)
	Control	1.8 (6.9)	6.6 (6.6)	1.9 (6.9)	5.7 (5.2)
Knee Flx*#μπ	**Train**	-60.6 (6.1)	-82.6 (10.0)	-59.6 (8.2)	-82.0 (11.4)
	Control	-54.4 (7.6)	-76.3 (12.2)	-53.7 (8.6)	-69.0 (9.7)
Knee Abd*	**Train**	-13.6 (6.3)	-15.5 (6.7)	-13.0 (6.0)	-15.0 (5.8)
	Control	-12.4 (7.1)	-15.2 (7.4)	-13.2 (5.1)	-16.3 (6.9)

* significant difference between movement type
# significant difference between testing time
μ significant difference between training group
π significant interaction between movement type, testing time and training group

A main effect of testing time on peak stance phase knee flexion was also noted (p = 0.033) (Table 3.3). Greater peak stance knee flexion was evident pre- compared to post-neuromuscular training. No significant differences (p > 0.05) for initial contact hip (p = 0.077, 1 - β = 0.426 and d = -0.36) and knee flexion (p = 0.800, 1 - β = 0.057 and d = 0.06), or hip adduction (p = 0.370, 1 - β = 0.143 and d = -0.21) and knee abduction (p =

0.889, 1 - β = 0.052 and d = 0.04) were exhibited between testing times. Furthermore, no significant differences were exhibited between testing times for peak stance hip flexion (p = 0.219, 1 - β = 0.229 and d = -0.24), adduction (p = 0.413, 1 - β = 0.127 and d = 0.17) and knee abduction (p = 0.890, 1 - β = 0.052 and d = 0.04).

Table 3.4. Initial Contact Hip and Knee Rotations

		Pre		**Post0**	
		Single	**Double**	**Single**	**Double**
Hip Flx*	**Train**	32.4 (7.1)	41.8 (8.6)	35.0 (5.6)	42.3 (5.8)
	Control	31.0 (6.1)	40.6 (7.2)	34.5 (8.4)	40.5 (6.0)
Hip Add*	**Train**	-8.4 (4.4)	1.2 (3.4)	-8.4 (5.3)	0.8 (4.9)
	Control	-8.5 (3.8)	-0.5 (5.5)	-7.4 (4.7)	1.1 (4.4)
Knee Flx*	**Train**	-17.3 (5.6)	-26.1 (7.4)	-16.0 (6.2)	-26.8 (8.2)
	Control	-14.0 (6.8)	-22.7 (8.7)	-13.4 (8.2)	-25.8 (9.7)
Knee Abd	**Train**	-5.1 (3.2)	-5.1 (3.7)	-4.8 (3.0)	-5.4 (4.2)
	Control	-5.1 (2.3)	-5.6 (3.6)	-5.0 (2.9)	-6.0 (3.0)

* significant difference between movement type

The main effect of movement type (unilateral and bilateral landings) had a significant impact on both initial contact and peak stance hip and knee postures (Tables 3.3 and 3.4). At initial contact, bilateral landings resulted in significantly greater hip (p < 0.001) and knee flexion (p < 0.001) and hip adduction (p < 0.001) compared to the unilateral landings. Post hoc analysis revealed significantly greater initial contact hip (p < 0.001) and knee flexion (p < 0.001) and hip adduction (p < 0.001) during bilateral landings compared to the unilateral landings at both the pre- and post-training time points. No significant difference, however, was observed between landing types for initial contact knee abduction posture (p = 0.150, 1 - β = 0.299 and d = 0.26). Significantly greater peak stance phase hip flexion (p < 0.001) and adduction (p < 0.001) were observed in the bilateral compared to unilateral landings. During bilateral landings, significantly greater peak stance phase knee flexion (p < 0.001) and abduction (p < 0.001) postures were evident compared to unilateral landings. Furthermore, post hoc analysis revealed significantly greater bilateral peak stance hip ($p < 0.001$) and knee flexion ($p < 0.001$), as well as, hip adduction ($p < 0.001$) and knee abduction ($p < 0.001$) during the bilateral landings at both the pre- and post-training time points compared to the unilateral landings.

DISCUSSION

Despite their increased quantity and quality, injury prevention programs have not diminished ACL injury rates or their associated sex disparity.[2] Currently, the success of such programs has been based on their ability to correct “risky” lower limb biomechanics during the execution of bilateral jump landings.[44, 158] It has remained largely unknown, however, as to whether similar modifications were possible for unilateral landings. Considering substantial differences exist in the lower limb biomechanical profiles between these two landings[63, 163, 176] and that ACL injuries occur more frequently during unilateral landings[167], failure to include such tasks when assessing intervention efficacies seems problematic. By comparing lower limb biomechanical adaptations between bi- and uni-lateral landings arising via a standard six-week neuromuscular-based ACL injury prevention program, the current study addressed this critical knowledge gap directly.

Outcomes of the current study suggest that the trained adaptations in lower extremity landing mechanics are substantially different between unilateral and bilateral jump landings. Following the ACL-injury prevention program, trained participants exhibited greater peak stance knee flexion posture during bilateral landings, but no significant differences were evident during unilateral landings as compared to the control participants. Furthermore, no significant differences were exhibited for either landing type prior to training. The current findings suggest that the trained participants retained peak sagittal plane knee joint posture during bilateral landings following a neuromuscular-based injury prevention program. The training participants, however, do no appear to transition similar retention of the peak sagittal plane knee posture to unilateral landing tasks following the injury prevention program. Conversely, the control participants adopted an extended knee posture during the bilateral landings after the six-week training period. The extended landing posture exhibited during the unilateral landings may increase ACL injury risk during these maneuvers. A more extended lower extremity landing posture has been shown to result in increased anterior tibial loading, which in turn increases ACL strain.[35] Thus, it could be both anterior tibial loading and resultant ACL strain may remain dangerously high during unilateral landings following training and further work is need to determine if current injury prevention strategies have the potential to reduce ACL loading during such tasks. We of course only tested safe, non-injurious movements, rendering such statements speculative at best.

Further interpretation of the statistical analysis may suggest that the ACL injury prevention program did not produce significant lower extremity biomechanical adaptations. As noted, the omnibus ANOVA suggested the training participants produced greater peak stance knee flexion during bilateral jump landings as compared to the control participants following training, while no significant differences were evident prior to training. Analysis of the effect size, however, may conflict these findings. We noted a moderate effect in the difference of peak stance knee flexion between the control and training participants at the pre-training time point. Interestingly, this may suggest that the significant difference displayed in peak stance knee flexion of the training group was evident prior to training and not a result of the ACL injury prevention intervention. These conflicting results highlight a need for further study, especially neuromuscular-based injury prevention programs with greater subject participation.

Consistent with previous findings, we noted significant differences in hip and knee kinematics between bilateral and unilateral landings.[63, 163, 176] Specifically, greater hip and knee flexion were demonstrated during the bilateral landings. Given these results, we suggest that current injury prevention efforts that focus on training-induced adaptations during bilateral landings may be over-generalizing their findings by not accounting for other sports relevant landings. The fact that current ACL injury prevention methods did not produce beneficial adaptations during unilateral landings supports this contention. To improve the effectiveness of ACL-injury programs, training programs may need to cater more effectively to and have their impact assessed during unilateral landings, as they are thought to pose the greatest risk of ACL injury.[167] Neuromuscular-based ACL injury prevention programs should of course continue to include techniques that aim to modify bilateral landings, since these tasks are equally common in sports activity and may still promote injurious knee joint mechanics. During bilateral landings, for example, greater peak stance knee abduction postures are evident compared to unilateral landings, suggesting they may still induce risky ACL load states.[95] Extensive work now appears necessary to determine the training exercises and components necessary to successfully modify “high-risk” lower limb biomechanics for each landing type.

It should be noted that the more extended posture exhibited during the unilateral compared to bilateral landing may be characteristic of this movement type, possibly rendering it non-modifiable, at least based on current training practices. When landing from a jump, athletes tend to decelerate their center of mass down the kinetic chain from larger, proximal to smaller, distal segments.[145] During the bilateral landings, deceleration of the center of mass would be “shared” by both limbs as control is transferred distally down the kinetic chain from the core musculature. During the unilateral landings, however, the landing limb only decelerates upper body segment inertias. A more extended landing posture during the unilateral tasks may thus be necessary to prevent collapse [145] that would otherwise occur by overtaxing the sagittal plane muscular (quadriceps and hamstrings) support system. Although injury prevention programs may improve lower sagittal plane muscle strength and subsequent support during unilateral landings, it is currently unclear whether such improvements are adequate to afford increased hip and knee flexion while still enabling successful task execution. Future work is needed to determine if the extended posture during unilateral landings is indeed a modifiable characteristic within ACL-injury prevention modalities, and whether such modifications, if possible, still afford successful performance of the task

Our findings are in direct contrast to previous data that demonstrated increased hip flexion and reduced knee abduction posture after training in females performing bilateral landings.[158] Reasons for this discrepancy are not immediately evident. One difference to note, however, is the experience of the athletes tested in each instance. We tested and trained only recreational athletes. These athletes may utilize an inconsistent movement strategy due to large variations in strength and neuromuscular control, as well as lack of experience.[103, 141] Previous injury prevention programs have been completed in more competitive athletes, who may possess refined neuromuscular control strategies [214] and greater lower extremity strength [32] compared to recreational athletes, possibly affording a more consistent movement strategy during the execution of complex movements.[103, 141, 214] Thus, competitive athletes might be able to develop more effective neuromuscular control strategies within the standard six-week training period, allowing them to demonstrate greater neuromuscular adaptation. It should be noted, however, that recreational athletes do consistently tear their ACLs[75] and thus similarly warrant effective ACL injury prevention programs. It may be that recreational athletes require longer training periods or a greater number of weekly sessions to adequately refine their integrative central and peripheral control strategies during complex, dynamic movements. The tailoring of future training methodologies to participant skill and/or experience levels thus appears worthy of further exploration.

A potential drawback of the present study was the relatively high-rate of subject attrition. Although, the loss to follow up was considerably higher than expected[158] adequate group size was obtained based on *a priori* power calculations. With that in mind, we feel that we can still interpret the statistical findings with confidence. Another possible limitation of the present study was the fact the investigator was not blinded to the participants' group status, which may have introduced bias into the study. The lack of blinding may have resulted in investigator influence during the data collections and possibly introducing bias.

Conclusion

Following a neuromuscular-based ACL injury prevention program, recreational athletes retained stance phase knee flexion magnitudes during bilateral landings. Similar training-induced retention, however, did not appear evident for unilateral movements. To reduce current ACL injury rates and their associated sex-bias, training programs may need to include strategies that successfully modify “high-risk” knee joint biomechanical profiles during both bilateral and unilateral movements. With lower limb joint biomechanical profiles being significantly different between unilateral and bilateral movements, similarly different training strategies may be needed to produce successful adaptations in each instance. Our current training-induced adaptations differed from previous injury prevention programs, possibly stemming from differences between study populations used. Further investigation of the potential need to tailor training strategies to participant skill and experience level may now be warranted.

CHAPTER 4

Comparative adaptations of lower limb biomechanics during uni-lateral and bi-lateral landings after different neuromuscular-based acl injury prevention protocols.

ABSTRACT

Current ACL injury prevention strategies are comprised of a series of specific training modalities, which aim to modify specific biomechanical factors such as a reduction in knee abduction posture and load, and increase knee flexion posture. While potentially valuable, these current training methodologies are lengthy and exhaustive, hindering participant compliance that may limit overall effectiveness. It has not been established whether similar biomechanical adaptations can be achieved with a shorter and potentially more compliant training protocol. The purpose of this study was to examine the extent to which core stability/balance and plyometric training, when used as single training modalities, can modify “high-risk” landing biomechanics compared to the standard neuromuscular and no training models. Forty-three subjects were included in the final analysis. Subjects had hip and knee three-dimensional biomechanics analyzed during a series of uni- and bi-lateral jump landings immediately prior to and following a six-week neuromuscular (NM, CORE or PLYO), or no training (CON) programs. Subject-based mean values of sagittal and frontal plane kinematics and kinetics were submitted to three-way repeated measures ANOVAs to test for the main and interaction effects of training group, landing type and testing time. Significantly greater peak knee flexion was evident in the NM group following training, during both bilateral and unilateral landings. The PLYO group demonstrated greater knee flexion and reduced hip adduction angles, and decreased knee abduction moment post-, but not pre-training during bilateral landings. Significant modifications were not evident during the unilateral landings. The CON group had significantly greater hip adduction moment and less peak stance knee abduction moment during the unilateral landings, but not during the bilateral landings post-training. The current outcomes suggest significant biomechanical changes may be possible via an isolated, i.e. plyometric, training component. The benefits, however, may not be evident across all landing types, and may be limited to simplistic, bilateral landings. An integrated, standard neuromuscular training model may have greater potential to improve landing biomechanics during unilateral landings. Future research remains warranted to develop shorter integrated training protocols that maximize participant compliance and ensure promotion of safe lower limb landing biomechanics.

INTRODUCTION

Anterior cruciate ligament (ACL) injury prevention programs aim to promote safer dynamic knee joint loading during sports-related movements to prevent the short- and long-term joint debilitation associated with ligament rupture.[81] Recent cadaveric [24, 127], videographic [29, 167] and biomechanical[120] evidence suggests that the majority of ACL injuries stem from coupled anterior tibial shear force and dynamic knee valgus and/or rotational loading during single-leg landings. Injury prevention protocols have been developed to modify these high-risk knee mechanical profiles, as they are amenable to training[17], demonstrate sex-dependence[140, 143, 195], and prospectively predict ACL injury risk.[98, 248] Current prevention strategies aim in particular to produce greater hip and knee flexion, reduce resultant shear loading, and decrease dynamic valgus motions (hip adduction, and knee abduction and rotation) and loads (external knee abduction and rotation) during landing. These prevention models, while still in their relative infancy, have promoted successful biomechanical modifications during dynamic landings.[95, 99] Decreased knee abduction posture and load, and increased knee flexion posture, in particular, have been evident following exposure to an injury prevention program.[44, 157, 158] In spite of reported early success of these injury prevention programs, however, the ACL injury rates have endured.[2] Further, female athletes remain 2-8 times more likely to suffer a non-contact ACL injury compared to males, competing in similar activities.[2, 81]

Current ACL injury prevention strategies are comprised of a series of specific training modalities (core stability/balance, plyometric, resistance, and speed) aimed toward promoting safer lower limb biomechanical profiles.[95, 158] Trained adaptations, however, vary across prevention programs, potentially stemming from the specific training modalities used.[157] Both core stability and balance[40], and plyometric training[95, 126], when combined with resistance exercises, have been shown to produce favorable adaptations in lower limb biomechanics.[157] Specifically, plyometric training increased knee flexion during a bilateral drop jump, whereas, core stability improved knee flexion posture during a medial drop landing.[157] Modifications stemming from core stability and plyometric, however, have not been consistent across all studies[179, 182, 219] and may be dependent on the training modalities performed. Previous data[157, 171] suggests integrated training, the use of a combination of two or more training components, is required for beneficial modifications. As a result, current training methodologies are lengthy, hindering participant compliance.[160] A recent injury prevention protocol, however, found core stability training decreased frontal and sagittal plane moments during the loading phase of a sidestep-cut in male athletes.[49] To date, it has not been established if similar adaptations can be achieved with either core stability or plyometric training used in isolation in female athletes.[171] Understanding how, or if, specific injury prevention modalities work in isolation would facilitate the development of a more compact and efficient training model. A shorter training model that produces the same beneficial training modifications may address and combat the compliance issues that are a known limitation of current strategies[160], eventually reducing the non-contact ACL injury rate.

Currently, assessment of ACL injury prevention efforts most often occurs during overly-simplistic, bilateral landing movements.[157] Little is known, however, regarding whether trained biomechanical adaptations are possible for unilateral landings.[157] Unilateral landings, however, compromise approximately 70% of actual sports landings, are a common vehicle for ACL injury[29, 100 167], and display significant joint biomechanical differences compared to bilateral landings.[63, 163, 176] Understanding if either core stability or plyometric training when used in isolation, and not paired with resistance exercises, can increase hip and knee flexion, or decrease dynamic valgus during unilateral landings will thus directly benefit the current prevention model. With that in mind, the purpose of this study is to examine the extent to which core stability/balance and plyometric training, when used as single training modalities, can modify "high-risk" landing biomechanics compared to the standard neuromuscular and no training models. We hypothesized that all athletes completing an injury prevention protocol (core stability and balance, plyometric and standard neuromuscular), but not the no training group, will display significantly greater peak hip and knee flexion angles and reduced peak flexion moments immediately following completion of the respective training protocols. Only the core stability/balance and standard neuromuscular participants, however, will display significantly reduced peak hip adduction angle and moment following training, whereas, the plyometric and standard neuromuscular participants will substantially reduce knee abduction angle and moment.

METHODS

Subjects:

Previous data comparing sagittal and frontal plane hip and knee kinematics of ACL injured and uninjured female athletes was used for an *a priori* power analysis, which indicated 13 subjects per group were needed to achieve 80% statistical power.[98] To ensure adequate sample size, we collected data on forty-three training participants, and a smaller number of no training (13) participants. Fewer subjects were recruited for the latter group, as similar noncompliance issues were not anticipated. All subjects were currently participating on school or club athletic teams involved in high-risk activities (e.g. basketball, field hockey, soccer, and volleyball). Potential participants who reported: (1) a history of previous knee injury or surgery, (2) pain in the lower extremity prior to testing or training, (3) a recent injury to the lower extremity (previous 6 months), and/or (4) a current pregnancy were excluded. Before testing, research approval was gathered from the University Institutional Review Board and written consent was obtained from all participants. All subjects also had leg dominance assessed prior to testing, which was defined as the leg which they could kick a ball the furthest.[138] Subjects wore spandex tights and their own athletic shoes during all data collections.

Experimental Design

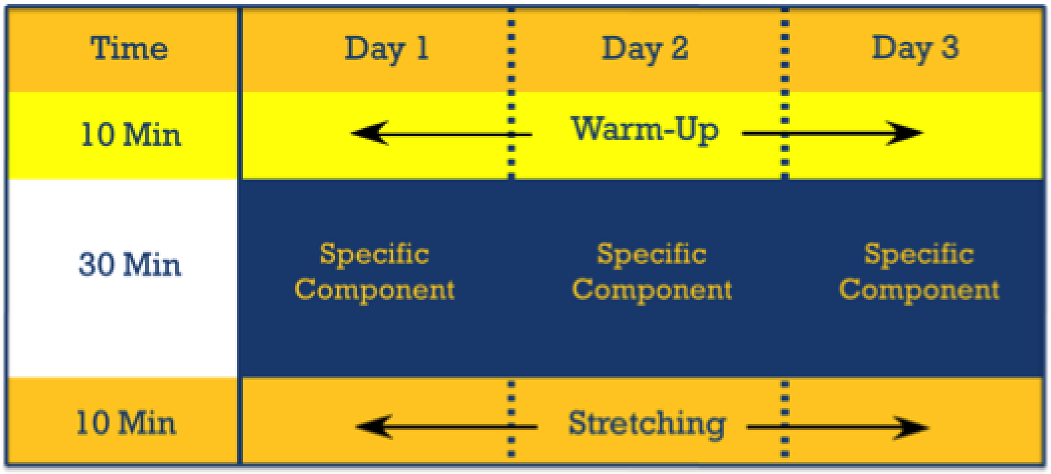
A pre-test post-test study design was used to test key hypotheses. Subjects were required to complete two testing sessions, immediately prior to and following neuromuscular training. Following the initial testing session, eligible participants were randomly allocated into one of four groups (Group 1: standard neuromuscular, Group 2: core stability and balance, Group 3: plyometric and Group 4: no training). The second testing session occurred immediately following (within two days) the six-week training protocols (Groups 1- 3), or after a six-week break (Group 4).

Neuromuscular Training

The training programs consisted of either a 60-minute standard neuromuscular or 20-minute isolated component protocol. Additionally, all training programs asked the subjects to perform an active warm-up (jogging, stretching, side-shuffle and backwards run) and self-selected stretching for approximately 10 minutes immediately before and after each session. All training programs, however, required three sessions per week over the six-week training period, for a total of 18 sessions. To successfully complete the training, each subject was required to participate in at least 16 of the 18 possible training sessions.[99, 158] During the training period, the control participants were asked to continue their normal daily activities between testing sessions and did not receive any training.

The standard neuromuscular training program (NM) was based on the following components: core strength and balance, plyometrics, resistance, and speed training. The training components were chosen from previous prevention techniques touted to be effective at reducing the biomechanical measures associated with ACL injury.[95, 158] Each NM training session lasted 60 minutes and was made up of three specific 20-minute components. The core strength and balance exercises were performed first in every session because the proprioception and postural control benefits of this component may be particularly important during dynamic landings.[155] Furthermore, poor core conditioning has been shown to lead to faulty landing mechanics[155] and linked to non-contact ACL injury.[221] The remaining training components (plyometrics, resistance, and speed training) were varied systematically across days to limit disinterest and/or fatigue of components occurring later in the session.[158] The training schedule, however, was consistent between weeks and subjects (Figure 3.1).

The isolated component training programs (CORE and PLYO) consisted of sessions that lasted approximately 20 minutes (Figure 4.1). The CORE exercises were derived from previous core strength and balance training programs[40, 44, 126, 157] with a goal to attain core strength levels that allow the subject to maintain balance and posture during the successful execution of landing tasks. The CORE component focused on increased coordination, strength and stability of the lumbopelvic musculature. The PLYO exercises were derived from programs shown effective at reducing biomechanical measures associated with ACL injury [44, 95, 99, 158]. The underlying goal of this modality was to develop proper landing technique (e.g. soft athletic landings with deep knee and hip flexion) and to improve dynamic control of the center of mass[160]. To achieve these goals, soft athletic landings were emphasized during double and single-leg jump landings tasks to develop sound athletic position and adequate control of center of mass.



Time	Day 1	Day 2	Day 3
10 Min	← Warm-Up →		
30 Min	Specific Component	Specific Component	Specific Component
10 Min	← Stretching →		

Figure 4.1 The weekly schedule for the six-week isolated component (CORE or PLYO) training programs consisting of exercises from either core stability and balance, or plyometric components.

The goal of all training programs (NM, CORE and PLYO) was to improve dynamic knee joint loading through performance of athletic maneuvers in a safe, efficient manner.[158] At all times during the training protocol, individuals skilled in the identification of proper form of a given exercise stressed correct technique (e.g., for landing: deep bending of the knees upon landing and proper alignment of the knees over the balls of their feet and chest over their knees) by providing constant verbal and visual encouragement and feedback.[95, 160] The early training sessions were used to establish correct movement technique (Phase 1) before progressively increasing volume and intensity of exercise

(Phase 2 and 3).[99] Performance of athletic maneuvers in an efficient manner was used to establish the underlying goal of the training program, which was to improve dynamic knee joint loading. Further specifics (e.g exercises and program goals) of all neuromuscular training programs are presented in detail in the Appendix A.

Neuromechanical Testing

During a series of single- and double-legged jump landings, subjects had synchronous bilateral three dimensional (3D) lower limb (hip, knee and ankle) joint kinetic and kinematic data recorded. For all jump landings, ground reaction force (GRF) data was captured with two force platforms (AMTI OR6, Advanced Mechanical Technology Inc., Watertown, MA) embedded in the floor, while eight high-speed (240 fps) optical cameras (MX-13, Vicon, Lake Forest, CA) recorded synchronous lower limb motion data. The subject began the jump landing sequence standing a distance equal to the length of their dominant limb from the front edge of the force platform. They were then required to jump over a 17 cm box during the flight phase before landing only on the requisite force platform for each landing.

The single-leg jump-landing task required subjects to perform one of two (L1 or L2) pre-defined, randomly ordered landings.[31, 34] For L1, subjects jumped forward, landed only on their left foot and then aggressively jumped laterally to the right, while for L2, subjects jumped forward, landed on their right foot and immediately jumped laterally to the left (Figure 2.1).[34] For the double-leg landing task, subjects were required to jump forward, land with one foot on each force platform, and immediately perform a maximal vertical jump upon landing. Maximal vertical jump height following the landing was calculated based on the time in air, using a uniform acceleration equation shown to have good intersession reliability.[150] Subjects were required to perform five successful landings of each jump-landing task (L1, L2 and vertical) during the protocol.

Biomechanical Analyses

Lower extremity joint rotations were quantified for all jump landings based on the 3D coordinates of thirty-one (14 mm diameter) precisely attached reflective skin markers (Figure 2.2).[31] The markers were attached and secured by a single experimenter (TNB) to pre-determined anatomical landmarks via double-sided tape and hypoallergenic, air-permeable cross elastic tape (Cover-Roll Stretch, BSN medical GmbH, Hamburg, Germany). To prevent excessive movement during landing, attachment of markers over areas of large muscle/tissue mass was avoided.

Following marker placement, the subject stood in a stationary (neutral) position while a high-speed video recording was taken. From the stationary recording, Visual 3D v4.00 software (C-Motion, Rockville, MD) was used to create a kinematic model comprised of seven skeletal segments (bilateral foot, shank and thigh segments and the pelvis) with 24 degrees of freedom. In the kinematic model, the pelvis was defined with respect to the global (laboratory) coordinate system and assigned six (three translational and three rotational) degrees of freedom.[138, 139, 242] Hip[20], knee[83, 228], and ankle[242] joint centers and associated orthogonal local segment (3 degrees of freedom) coordinate systems were defined in accordance with previous literature and our own previous work.[20, 83, 228, 242]

During each jump landing, synchronous 3D GRF data was collected at 1200 Hz, and along with 3D marker trajectories were low pass filtered with a fourth-order Butterworth filter at a cut-off frequency of 12 Hz.[34, 142] Visual 3D software was used to solve the recorded 3D marker trajectories recorded during each jump landing trial for the lower limb joint rotations at each time frame. Resultant hip, knee and ankle joint rotations were expressed relative to the subject's static (neutral) 3D posture.[110, 134, 138] The filtered kinematic and GRF data were processed using conventional inverse dynamics analyses to obtain 3D intersegmental forces and moments at each lower limb joint.[235] The segmental inertial properties were defined in accordance with the work of Dempster.[57] Hip and knee 3D intersegmental forces were transformed to respective distal segment reference frames (femoral and tibial) and anterior-posterior, medial-lateral and compression-distraction forces were calculated. The resultant intersegmental moments at the hip and knee were characterized as flexion-extension, abduction-adduction and internal-external rotation moments with respect to the cardanic axes of their respective joint coordinate systems.[138, 139] All kinetic variables were normalized to participant body mass (kg) and height (m). The kinematic and kinetic data were time-normalized to 100% of stance (heel strike to toe-off) and re-sampled at 1% increments (N = 101) with heel strike and toe-off defined as the instant GRF first fell below and exceeded 10 N, respectively [31].

Statistical Analysis:

A one-way ANOVA was used to compare baseline subject characteristics (height, weight, and age) between all groups (NM, CORE, PLYO and CON). Specific hip and knee kinematic and kinetic parameters were identified for pre-planned statistical treatment based on their previously suggested link to ACL injury.[98, 138] Specifically, the dependent variables were peak hip and knee flexion-extension, and abduction-adduction angles and moments between 0% and 50% of the stance phase. Stance phase biomechanics were considered over the first 50% only, as ACL injury is suggested to occur within this time frame.[81] Subject-based mean values of each kinematic and kinetic dependent measure were submitted to a three-way ANOVA to test for the main effects of and possible interactions between group (NM, CORE, PLYO and CON), landing type (unilateral and bilateral landings) and testing session (pre- and post-training). In instances where statistically significant differences were observed, Bonferroni pairwise comparisons were used. Significant interaction effects were submitted to one-way ANOVAs stratified by training group (three-way) or one-way ANOVA collapsed by the third variable (two-way), and followed up by t-tests to test simple main effects. An alpha level of 0.05 was used to denote significance for each statistical comparison.

RESULTS

The final statistical analysis included forty-three subjects (Table 4.1) as subject attrition was greater than expected for both core and standard neuromuscular training groups. Specifically, four NM and nine CORE subjects that were excluded because they did not complete an adequate amount of training or the requisite number of testing sessions to be included in the final analysis. No statistically significant differences in the baseline subject characteristics were evident, suggesting successful randomization (Table 4.1). Thus, we interpreted our remaining statistical comparisons with confidence.

Table 4.1. Baseline Subject Characteristics

	NM (N = 10)	**CORE** (N = 7)	**PLYO** (N = 13)	**CON** (N = 13)	**p-value**
Age	14.1 ± 1.2 years	15.0 ± 0.6 years	14.8 ± 0.6 years	14.7 ± 2.6 years	0.623
Height	1.63 ± 0.08 m	1.66 ± 0.07 m	1.64 ± 0.02 m	1.62 ± 0.06 m	0.596
Weight	50.6 ± 8.5 kg	61.7 ± 11.2 kg	59.5 ± 8.9 kg	53.9 ± 10.1 kg	0.055

The ANOVA revealed a significant three-way interaction for peak knee flexion angle ($p = 0.037$) (Figure 4.2 and Table E.8). Post hoc analyses revealed the NM participants had significant effect of condition ($p = 0.026$). The pairwise comparisons revealed the NM participants displayed greater peak knee flexion angle during the bilateral ($p = 0.027$), but not during the unilateral landings ($p = 0.071$, $1 - \beta = 0.456$, and $d = 0.645$) at the post-training compared to the pre-training time point. The PLYO participants, however, exhibited a significant testing time and landing type interaction ($p = 0.027$), but the pairwise comparisons revealed no significant difference of peak stance knee flexion during the bilateral landings ($p = 0.064$, $1 - \beta = 0.467$ and $d = 0.565$) or unilateral landings ($p = 0.126$ and $1 - \beta = 0.327$) at the post-training compared to the pre-training time point. No significant differences of peak knee flexion angle, however, existed between the pre- and post-training time points for the CORE ($p = 0.128$ and $1 - \beta = 0.319$) and CON ($p = 0.299$ and $1 - \beta = 0.170$) groups. Interestingly, there were no substantial differences between groups (NM, CORE, PLYO and CON) for either the bilateral and unilateral landings at either the pre- ($p = 0.190$, $1 - \beta = 0.403$ and $p = 0.253$, $1 - \beta = 0.345$) and post-training ($p = 0.236$, $1 - \beta = 0.359$ and $p = 0.904$, $1 - \beta = 0.082$) time points.

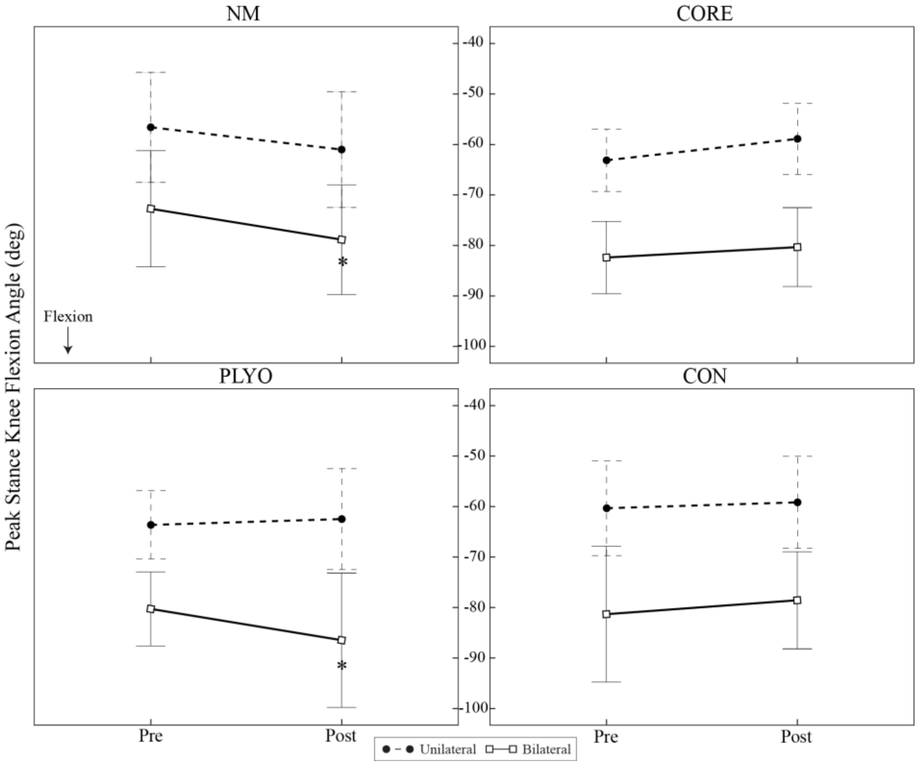


Figure 4.2 A plot comparing the mean Pre and Post peak stance knee flexion posture for both unilateral and bilateral landings between the NM, CORE, PLYO and CON participants. The NM training participants produced greater knee flexion during both the bilateral ($p = 0.043$) and unilateral ($p = 0.071$) landings at the post-training time point compared to the pre-training, whereas, the PLYO participants exhibited greater peak stance knee flexion during the bilateral landings ($p = 0.064$), but not the unilateral landings ($p = 0.176$) following training. * indicated significant difference ($p < 0.05$) from pre-training time point.

The ANOVA revealed a significant two-way interaction for peak hip flexion posture ($p = 0.017$) (Figure 4.4 and Table E.8). Further analysis indicated that during the bilateral landings, peak stance hip flexion was significantly greater at the post-training time point compared to the pre-training ($p = 0.002$), whereas, no substantial difference was evident between the pre- and post-training time points for the unilateral landings ($p = 0.389$ and $1 - \beta = 0.138$).

A two-way interaction was also evident for peak stance hip adduction posture ($p = 0.008$) (Figure 4.6 and Table E.8). Specifically, the PLYO participants displayed significantly less peak hip adduction angle ($p = 0.010$) at the post-training compared to the pre-training time point, whereas, no significant differences were evident for the NM ($p = 0.130$ and $1 - \beta = 0.320$), CORE ($p = 0.380$ and $1 - \beta = 0.127$) or CON ($p = 0.947$ and $1 - \beta = 0.050$) participants following training.

A three-way interaction was noted for the peak knee abduction moment ($p = 0.021$) (Figure 4.3 and Table E.9). Further analysis indicated that the PLYO participants significantly decreased ($p = 0.05$) peak knee abduction moment at the post-training compared to the pre-training time point. Conversely, the CON participants had significantly less peak stance knee abduction moment during the unilateral landings ($p = 0.005$) and not during the bilateral landings ($p = 0.351$ and $1 - \beta = 0.145$) at the post-training compared to the pre-training time point. The NM ($p = 0.682$ and $1 - \beta = 0.067$) and CORE ($p = 0.407$ and $1 - \beta = 0.118$) participants, however, displayed no significant difference in peak knee abduction moment between pre- and post-training time points. Furthermore, there were no substantial differences among groups (NM, CORE, PLYO and CON) for either the bilateral and unilateral landings at either the pre- ($p = 0.495$, $1 - \beta = 0.209$ and $p = 0.332$, $1 - \beta = 0.291$) and post-training ($p = 0.182$, $1 - \beta = 0.411$ and $p = 0.807$, $1 - \beta = 0.108$) time points.

A two-way testing time and group ($p = 0.018$) interaction was evident for peak hip adduction moment ($p = 0.031$) (Figure 4.7 and Table E.9). The CON ($p = 0.015$)

participants demonstrated significantly greater hip adduction moment following training, whereas, the NM ($p = 0.606$ and $1 - \beta = 0.077$), CORE ($p = 0.228$ and $1 - \beta = 0.206$) and PLYO ($p = 0.131$ and $1 - \beta = 0.320$) groups displayed no differences in the hip adduction moment between the two testing time points, pre- and post-training. Furthermore, a significant landing type and group ($p = 0.021$) interaction was evident for peak hip adduction moment. The pairwise comparisons, however, revealed that the NM ($p < 0.001$), CORE ($p = 0.049$), PLYO ($p < 0.001$) and CON ($p = 0.001$) groups all displayed significantly greater peak hip adduction moment during the unilateral compared to the bilateral landings.

There was no significant main effect of training group ($p > 0.05$) evident for peak stance phase hip and knee flexion, hip adduction or knee abduction angles or moments (Tables E.8, E.9 and E.10).

A main effect of testing time on peak stance phase hip flexion posture was noted ($p = 0.004$) (Figure 4.4 and Table E.8). Specifically, greater stance phase hip flexion angle was evident at the post-training time point compared to pre-training. No significant differences ($p > 0.05$), however, were evident for hip adduction, and knee flexion or abduction postures and moments, or hip flexion moment between the pre and post-training time points (Tables E.8, E.9 and E.11).

Movement type (unilateral and bilateral landings) had a significant impact on peak stance hip and knee angles and moments (Table E.8 and E.9). During the bilateral landings, significantly greater peak stance phase hip ($p < 0.001$) (Figure 4.4) and knee flexion ($p <$

0.001) (Figure 4.2) postures were evident compared to unilateral landings. Whereas, significantly decreased hip and knee flexion, and hip adduction moment was evident during the bilateral compared to unilateral landings (Figures 4.5, 4.7 and 4.8). No significant differences ($p > 0.05$), however, existed between the bilateral and unilateral landings for either peak stance hip adduction angle, or knee abduction angle and moment (Figures 4.3, 4.6 and 4.9 and Table E.12).

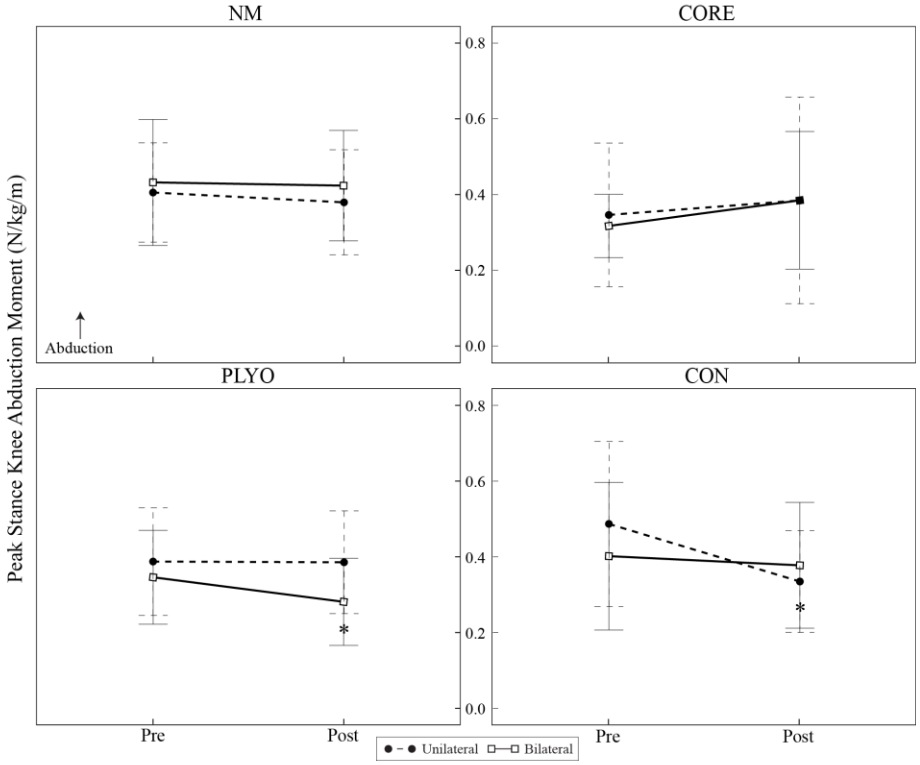


Figure 4.3 A plot comparing the mean Pre and Post peak stance knee abduction moments among the NM, CORE, PLYO and CON participants. The PLYO participants significantly decreased peak knee abduction moment at the post-training compared to the pre-training time point during the bilateral landings ($p = 0.039$), but not during the unilateral landings ($p = 0.983$). Conversely, the CON participants had significantly less peak stance knee abduction moment during the unilateral landings ($p = 0.008$) and not during the bilateral landings ($p = 0.434$) at the post-training compared to the pre-training time point. * indicated significant difference ($p < 0.05$) from pre-training time point.

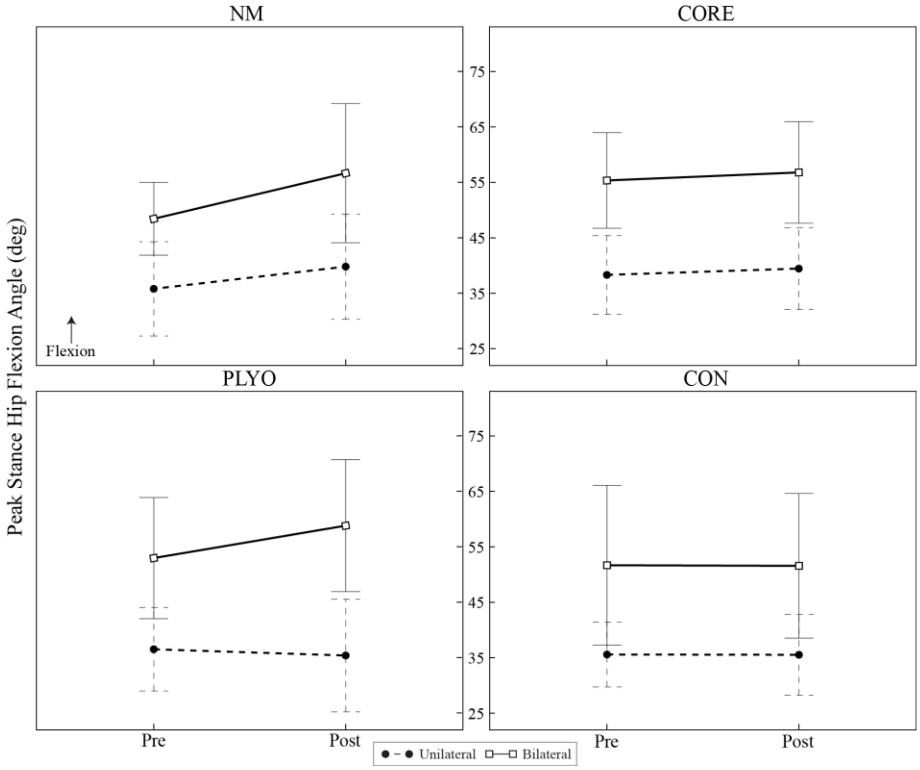


Figure 4.4: A plot comparing the mean Pre and Post peak stance hip flexion angle for both unilateral and bilateral landings among the NM, CORE, PLYO and CON participants.

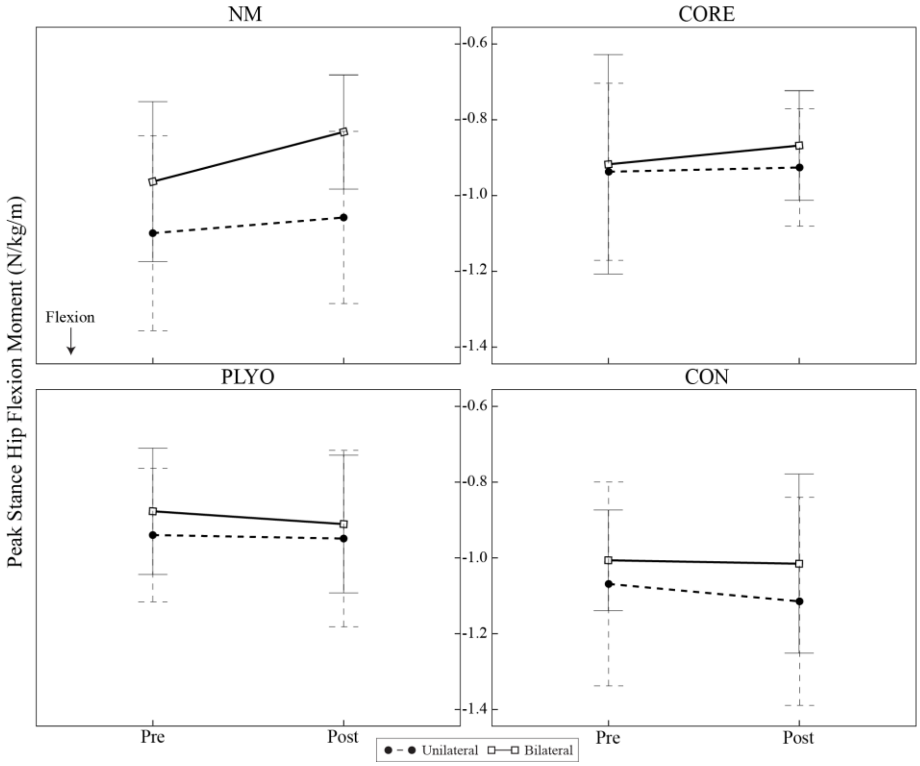


Figure 4.5: A plot comparing the mean Pre and Post peak stance hip flexion moment for both unilateral and bilateral landings among the NM, CORE, PLYO and CON participants.

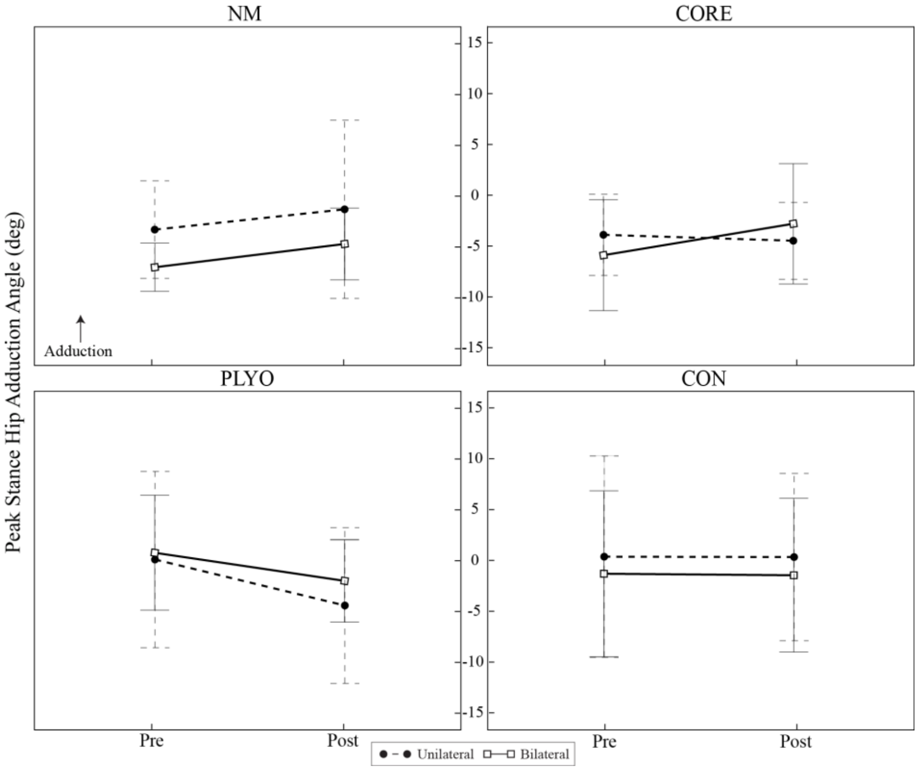


Figure 4.6: A plot comparing the mean Pre and Post peak stance hip adduction angle for both unilateral and bilateral landings among the NM, CORE, PLYO and CON participants.

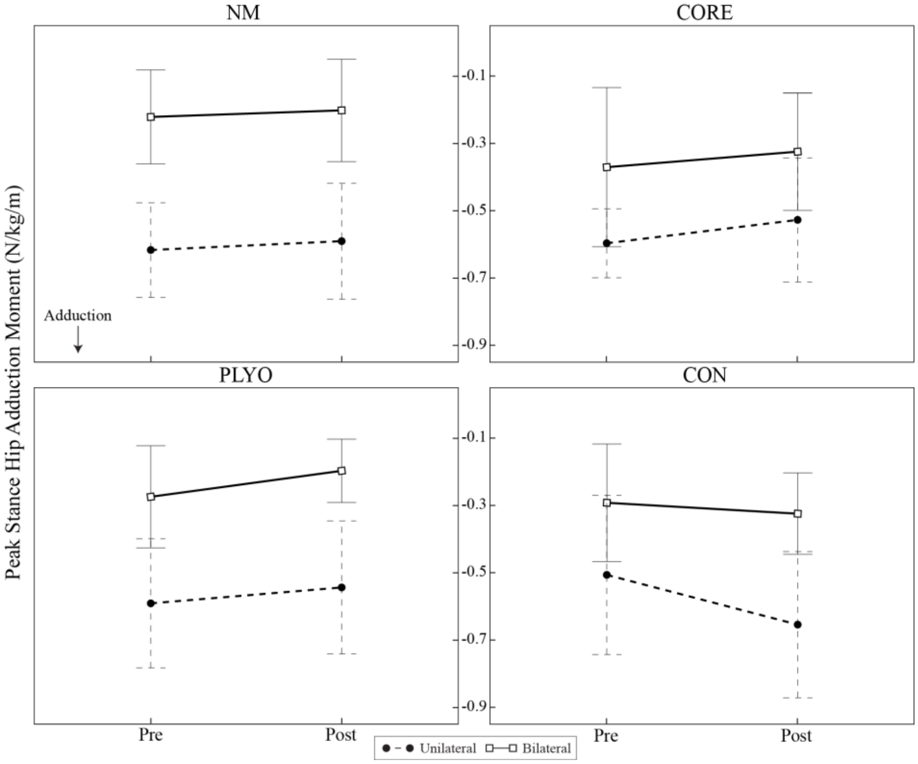


Figure 4.7: A plot comparing the mean Pre and Post peak stance hip adduction moment for both unilateral and bilateral landings among the NM, CORE, PLYO and CON participants.

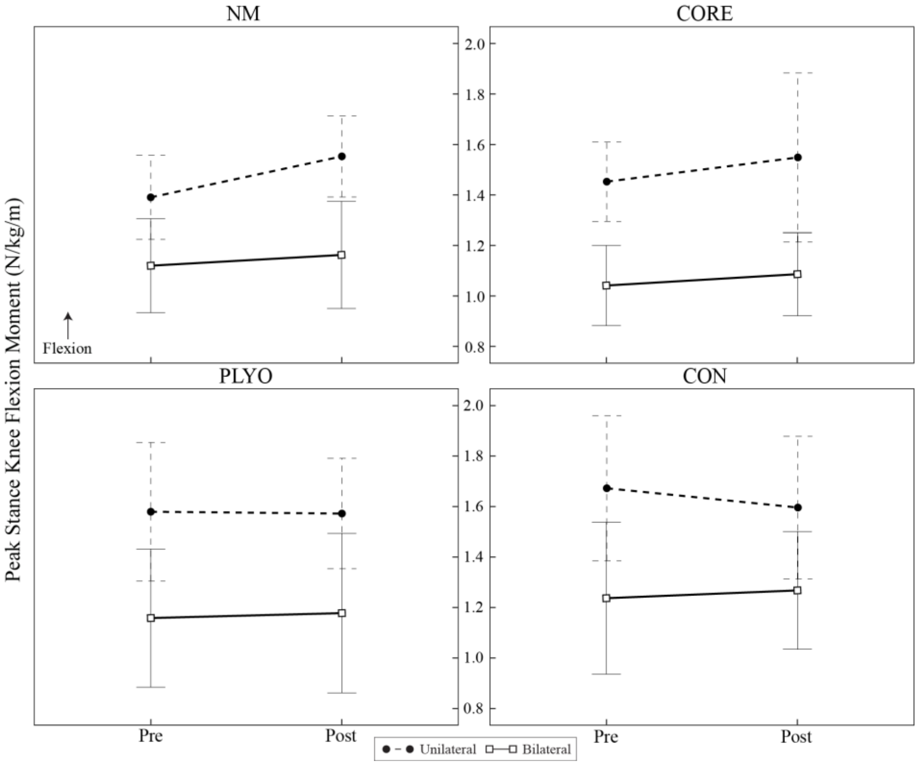


Figure 4.8: A plot comparing the mean Pre and Post peak stance knee flexion moment for both unilateral and bilateral landings among the NM, CORE, PLYO and CON participants.

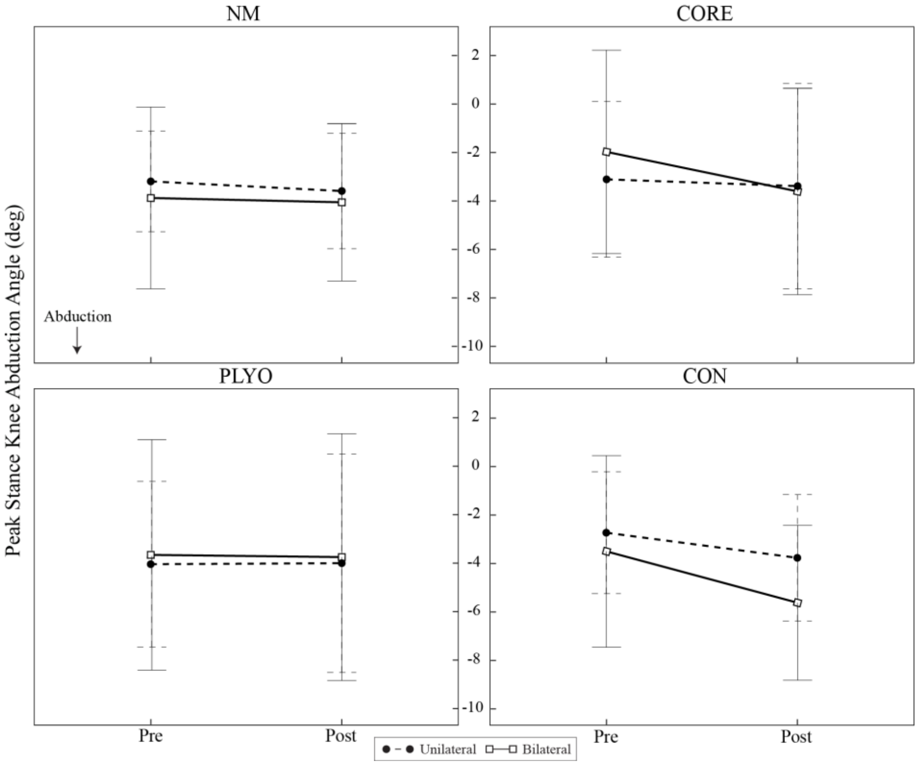


Figure 4.9: A plot comparing the mean Pre and Post peak stance knee abduction angle for both unilateral and bilateral landings among the NM, CORE, PLYO and CON participant.

DISCUSSION

It has been previously suggested that ACL injury prevention programs need to integrate two or more training components to produce beneficial modifications of lower limb landing biomechanics.[171] As a result, current training methodologies are lengthy, potentially hindering participant compliance and likely detracting from their overall success. The development of a shorter training protocol that produces the same beneficial trained modifications may combat these concerns, eventually reducing ACL injury rates. Previously, both core stability and balance, and plyometric components have been shown to produce trained biomechanical adaptations when paired with resistance training.[157] It has not been established, however, if either training modality, when used in isolation, can modify lower limb biomechanics in female athletes. This study examined the extent to which core stability and balance, and plyometric training, when used as single training modalities, can modify “high-risk” landing biomechanics as compared to the standard training model and no training, control, participants.

Outcomes of the current study suggest that training adaptations in lower limb mechanics are substantially different between injury prevention protocols. These findings are in agreement with previous experimental evidence[157] and support the contention trained biomechanical adaptations are dependent on the specific exercises performed. Specifically, both NM and PLYO participants displayed significantly greater peak knee flexion posture following training, whereas, the CORE and CON participants demonstrated no substantial change at the post-training time point. Landing with the greater knee flexion posture has been viewed as an important training-induced modification that may reduce “high-risk” sagittal plane ACL loading.[245] that the potential to reduce high-risk sagittal plane knee loads may thus be sensitive to the injury prevention modality undertaken, and possibly stems from the feedback and adjustments associated with each training component.[157]

To our knowledge, this study is the first to demonstrate that training modifications may be possible with the use of one isolated training component in competitive female athletes. These training adaptations, however, were not evident during all landing types. The PLYO group produced significant modifications of peak knee flexion angle during the bilateral landings following the six-week training period, but similar substantial sagittal plane kinematic adaptations were not evident during the unilateral movement. It appears plyometric-based ACL injury prevention programs can increase knee flexion posture during simplistic, bilateral landings. These substantial training adaptations, however, are not transferred to unilateral landings. During the loading phase of a bilateral jump landing, athletes can spread the demands of decelerating their center of mass across both limbs as they pass control of upper body segment inertias down the kinetic chain (i.e. from larger, proximal to smaller, distal segments).[145] During a unilateral landing, however, only the landing limb bares the responsibility of controlling the segment inertias as control is passed distally down the limb from the core musculature. That we saw significantly greater lower limb sagittal plane moments during the unilateral compared to the bilateral landings supports this contention. The demand placed on lower limb musculature, which is required to generate a torque that matches the magnitude of the external moment generated during a jump landing, significantly increases during a unilateral landing. Thus, it may be an extended landing posture is adopted during a unilateral landing to limit overloading the lower limb sagittal plane musculature and prevent the ensuing collapse that may occur as a result of greater flexion.[145] Since unilateral landings are consistently implicated within the injury mechanism, this limitation may be extremely problematic. Further work, however, is necessary to determine whether a potentially “safer” sagittal plane profile during unilateral landings is indeed, plausible based on demands of this task.

Current outcomes demonstrate that a “safer” sagittal plane landing biomechanical profile is possible with a standard NM training protocol. Specifically following the six-week training period, the NM participants displayed increased knee flexion posture during both bi- and unilateral landings. It seems that only the NM training, i.e. integrated, protocol has the potential to modify sagittal plane knee kinematics during unilateral landings. If unilateral adaptations are critical to injury reduction, it may be two or more components are essential, but that stipulates a lengthy protocol. Thus, it seems worthwhile to determine, which components of a NM program may be critical for the modification of lower limb biomechanics during unilateral landings. Potential benefits, however, may still be possible with isolated components if the training period is extended beyond the current six-week standard. Further work is necessary to test such tenets, which may ultimately aid with the development of a more effective injury prevention program.

Although, the NM training demonstrated the potential to modify knee flexion posture during unilateral landings a significant change was in fact, not evident following training.

It may be that the current NM training model is ineffective at modifying mechanics considered critical to injury reduction. This could be a plausible reason for the fact injury rates are not decreasing and warrants further investigation.

Trained sagittal plane knee kinematic adaptations were not currently evident following isolated CORE training. Myer et al.[157] demonstrated previously that peak knee flexion increased during a medial drop following a combined core stability and resistance program. It may be that CORE training requires integration with other training modalities to produce beneficial biomechanical adaptations, or simply may not produce beneficial effects. We cannot currently make definitive conclusions based on isolated CORE training because the current sample size provided inadequate statistical power. Further research may provide additional insights into biomechanical modifications following neuromuscular training with only core stability and balance exercises. Based on current outcomes, however, isolated CORE training may not be critical to successfully modify lower limb landing biomechanics during either bi- or unilateral landings.

Similar to the knee, substantial adaptations of sagittal plane hip kinematics were evident during the bilateral landing after the six-week training period. These training modifications, however, were not retained during the unilateral maneuver. It has been suggested that adequate lumbopelvic, “core”, musculature strength and conditioning is crucial to provide a proper foundation for force production of the lower extremity during dynamic motions.[174] Since the demands of decelerating the center of mass are placed entirely on the landing limb during a unilateral landing it may require greater core strength and conditioning, i.e. stronger support foundation, compared to the bilateral maneuver. Although this is currently speculative, as core strength was not directly measured, further work may be needed to understand the core strength and conditioning requirements to obtain subsequent biomechanical modifications during unilateral maneuvers. It is currently unclear whether increased hip flexion posture during a unilateral landing is even a modifiable characteristic. Abnormal hip control (i.e. extend hip posture and delayed flexion during landing), however, may play a crucial role in the non-contact ACL injury mechanism[86] and thus further work is need to identify training exercises that may facilitate hip flexion, as a means to reduce injury rate.

The current experimental evidence suggests an ACL injury prevention program has no substantial effect on either hip or knee flexion moment. The external knee flexion moment was found previously to decrease during a bilateral jump landing following a plyometric training protocol[117] and during a single-leg cut after balance training.[49] These outcomes, however, has been not consistent for all neuromuscular training programs.[90, 99, 158] The reason for this current discrepancy is not known, but may stem from task or population differences. Studies previously shown to modify knee flexion moments assessed program effectiveness during a simplistic, bilateral drop landing or with male athletes. Thus, future work is warranted to determine training modalities that produce beneficial modifications of the sagittal plane loading during unilateral landings of female athletes as it might decrease demand placed on the leg musculature and subsequent injury risk.

Reduced dynamic knee valgus loading during sports-related landings may be essential training modification that potentially decreases the non-contact injury rate. The current biomechanical[120 29, 167] evidence suggests that a majority of non-contact ACL injuries occur from lower limb neuromechanical patterns that coupled anterior shear force with dynamic knee valgus loading during single-leg cutting or landing maneuvers. Specifically, the injury may occur from valgus collapse[111], large knee abduction movements and possibly loads, during the landing phase. The current outcomes demonstrated that PLYO participants decreased peak knee abduction moment during the bilateral landings following the six-week training period, but these modifications were not transferred to the unilateral movement. The fact that the CON group displayed a substantial reduction in peak knee abduction moment during the unilateral landings, suggests it may indeed be an attainable training goal. Currently, we are not sure of the specific reason for why the CON group decreased knee abduction loading following training, but the participants may have developed a familiarity with the single-leg land and cut maneuver between the testing sessions. This familiarity may have allowed them to decrease the hazardous knee abduction moment. Since a unilateral maneuver may be representative of injurious scenario, future research is needed to determine specific injury prevention modalities, or a combination of explicit components, that decrease knee abduction loading during these landings.

Following the training programs PLYO participants decreased and CON increased peak hip adduction moment, while neither the NM nor CORE participants displayed a substantial change in hip adduction moment. These findings are in direct contrast to our hypotheses, which stated CORE and NM training would substantially improve hip frontal plane biomechanical profiles. Although, the reason for the discrepancy is not immediately known, it may stem from inadequate core stability. Since several of the muscles acting at the knee joint originate within the lumbopelvic region, which provides a crucial foundation for the lower extremity muscles[174], adequate core stability may be a necessity to obtain a reduction of hip adduction loading during landing. The current outcomes, however, do not support this contention and further research is needed to determine whether core stability and balance training provides beneficial lower limb biomechanical modifications that reduce ACL injury risk. Previously, Myer et al.[157] concluded that improvements in lower limb valgus posture may be related to feedback made during training and are not dependent on specific training exercises. This observation was not supported with the current findings, as frontal plane hip adaptations appeared dependent on the training modality. The current discrepancy may stem from differences in the task used to assess program effectiveness. Previously, Myer et al.[157] assessed lower limb biomechanics during bi- and unilateral landing stabilization tasks. It may be CORE training, which allows for immediate feedback during the performance balance/stabilization exercises does not transfer biomechanical modifications to a dynamic maneuver. The PLYO training, however, requires the performance of dynamic landings, which are more representative of the current assessment task and an injury scenario. Thus, it may be PLYO training is required to produce substantial modifications in frontal plane hip biomechanics during a dynamic landing task, whereas, CORE adaptations are limited to stabilizing maneuvers.

Currently adopted neuromuscular-based ACL injury prevention programs did not substantially reduce peak knee abduction posture. Specifically, no significant difference between the pre and post-training time points was evident for peak stance knee abduction angle for any of the training programs. This outcome is in direct contrast with previous ACL injury prevention literature, which suggests that training methods significantly reduce peak knee abduction angle.[157, 158] While the reason for the current discrepancy is not immediately known, it may stem from the landing task. Injury prevention programs that have previously decreased knee abduction posture have done so during a bilateral or unilateral landing stabilization task.[99, 157, 158] We currently employed a bilateral or unilateral jump landing, where the participant was required to land and either perform a bilateral jump or unilateral cut. It may be the tasks currently employed increased the demand place on the lower limb during the loading phase of the landing. Current training methodologies may be sufficient to reduce knee abduction posture while stabilizing during a landing, but cannot decrease knee abduction posture during a dynamic maneuver. Regardless, future research is needed to determine training methodologies that decrease knee abduction motion[99, 158] during dynamic single-leg land and cut movements, which may be a closer representation of an ACL injury scenario than the landing type currently employed to assess ACL injury prevention program effectiveness.

Conclusion

In conclusion, the current outcomes suggest significant biomechanical changes may indeed be possible from training with an isolated training component. Specifically, plyometric training may be an essential training component for modifying both sagittal and frontal plane landing biomechanics. The benefits of plyometric training, however, may not be evident across all landing types, as substantial alterations of landing biomechanics were only evident during simplistic, bilateral landings. The standard neuromuscular training model may have greater potential to improve landing biomechanics during unilateral landings. Further considering unilateral landings present the greatest risk of ACL injury, it may be that integrated training protocols, consisting of the combination of two or more training components, present as the most effective training model. With that said, future research remains warranted to develop shorter integrated training protocols that maximize participant compliance and ensure promotion of safe lower limb landing biomechanics.

CHAPTER 5

Trained quadriceps and hamstrings activation changes predict modifications of hip and knee biomechanics following an ACL injury prevention program.

ABSTRACT

Current injury prevention programs are thought to be a successful means for reducing ACL injury risk, through beneficial modification of lower limb neuromuscular control and resultant joint biomechanical strategies. The explicit training induced neuromuscular control adaptations that predict beneficial modifications in lower limb landing biomechanics is currently unknown, but this knowledge may correspond with a reduction in the non-contact ACL injury rate. Thus, the purpose of this study was to compare the relationships between training-induced changes in explicit lower limb neuromuscular control strategies and joint biomechanics elicited during unilateral landings following isolated core stability/balance, plyometric, standard neuromuscular and no training groups. Forty-three subjects had hip and knee three-dimensional biomechanics and lower extremity muscle activity recorded during a series of unilateral jump landings immediately prior to and following a six-week training (NM, CORE or PLYO), or no training (CON) programs. Average RMS activity of the lateral hamstrings, vastus lateralis, rectus femoris and gluteus medius, and VL:LH co-contraction ratio were calculated during the pre-activity phase for each jump landing. Multiple stepwise regressions were fit to determine pre-post training changes of muscle activation patterns

that predict changes in peak stance hip and knee biomechanics. For the NM group, lateral hamstrings pre-activity predicted peak stance hip flexion moment ($R^2 = 0.484$, $b = -0.742$ and $P = 0.025$), whereas, rectus femoris pre-activity ($R^2 = 0.447$, $b = -1.246$ and $P = 0.049$) predicted hip flexion moment for the PLYO group. Peak stance knee abduction angle was predicted by vastus lateralis pre-activity ($R^2 = 0.508$, $b = 1.540$ and P = 0.006) for the CON group and VL:LH co-contraction ratio ($R^2 = 0.685$, $b = -0.091$ and P = 0.022) for the CORE. The current outcomes suggest that NM and PLYO groups had trained activation modifications that predicted improved hip sagittal plane loading, while the CORE group had adaptations that decreased frontal plane knee motion. It may be future injury prevention programs can be composed of just CORE and PLYO exercises to promote biomechanical modifications that improve ACL loading.

INTRODUCTION

Anterior cruciate ligament (ACL) injury is a traumatic, debilitating event that is the largest problem in orthopedic sports medicine.[81, 191] Injury prevention programs that target the modification of high-risk lower limb neuromechanics have been developed to reduce the incidence of ACL injury and its associated sex-disparity. Female athletes are between 2 and 8 times more likely to suffer a non-contact ACL injury, which account for up to 80 percent of all ACL ruptures[29, 66, 144], compared to males participating in similar activities.[2, 81] Deleterious ACL loading is thought to stem from high-risk lower limb landing neuromechanics, or rather, ineffective neuromuscular control strategies that lead to hazardous joint biomechanics (i.e. joint kinematics and moments).[209] Experimental evidence suggests a non-contact ACL injury arises during rapid deceleration followed by landing on a single-leg, with the knee at/or near full extension while utilizing excessive quadriceps and reduced hamstring muscle activation[29, 111, 114, 167, 209] during the first 50 ms of the landing phase.[114] Therefore, the neuromuscular control strategies, which maintain dynamic joint stability, may have insufficient time to regulate muscle stiffness through reactionary patterns.[21] It may be preparatory muscle activity plays a greater role in dynamic joint stability,[62, 230] with explicit activation patterns predicting “high-risk” lower limb biomechanics.[172, 173] Current injury prevention programs are thought to be a successful means for reducing ACL injury risk [47, 117, 119, 231, 249], through beneficial modification of lower limb neuromuscular control[231, 249] and resultant joint biomechanical strategies.[44, 90, 158] In spite of these efforts, however, non-contact ACL injury rates have not been reduced.[2] Thus, the current injury prevention model may fail to successfully counter ineffective preparatory neuromuscular parameters that may govern injurious biomechanical profiles during landing maneuvers.

Neuromuscular-based ACL injury prevention protocols have been developed to modify high-risk lower limb neuromechanics. The current “standard” neuromuscular-based ACL injury prevention program is composed of a series of specific training modalities (core stability/balance, plyometric, resistance, and speed), with the intent to produce a “safer” neuromechanical profile. The specific neuromuscular modifications purported following injury prevention programs are greater gluteus medius[117] and hamstring activation [231, 249], reduced quadriceps activation[231], and improved hamstring to quadriceps co-contraction.[119] The lower limb biomechanical adaptations suggested to also occur following training are decreased knee abduction posture and load, and increased knee flexion posture.[44, 157, 158] Regardless of these modifications, the explicit training induced neuromuscular control adaptations that predict beneficial modifications in lower limb landing biomechanics is currently unknown. Knowing the explicit preparatory neuromuscular parameters to target within the injury prevention model that counter injurious biomechanical profiles may correspond with a reduction in the non-contact ACL injury rate.

While the standard ACL injury prevention program is considered effective, it is incredibly time consuming, which directly impacts participant compliance and overall program success.[160] Recently, trained modifications in lower limb biomechanics were viewed possible via two shorter prevention training protocols.[49] Improved knee flexion and reduced abduction posture during jump landings, for example, were evident following training methodologies that paired core stability with resistance exercises, and plyometric exercises with resistance training, respectively.[157] While this appears a step in the right direction, it remains unclear whether isolated core stability or plyometric training components could promote similar neuromechanical adaptations. If this were indeed the case, then a substantial reduction in training time and subsequent increase in participation and compliance may be possible.

In addition to identifying specific components of ACL injury prevention programs that promote safe lower limb neuromechanics, ensuring safe patterns are retained during sports relevant movements is critical to a reduction in injury rates. Until recently, training model success was limited to the ability to promote and maintain safe neuromechanical profiles during overly-simplistic, bilateral landings.[157] Unilateral landings, however, comprise approximately 70% of actual sports landings and are a common vehicle for ACL injury.[29, 100 167] It has also been shown that unilateral landings display significant joint biomechanical differences compared to bilateral landings.[63, 163, 176] It still remains unclear whether trained neuromechanical adaptations that may reduce the risk of ACL injury are possible during unilateral landing maneuvers. Therefore, it appears most appropriate to assess the viability of isolated core stability or plyometric training to reduce ACL injury risk during a unilateral landing.

Although, the experimental evidence suggests specific neuromuscular control strategies predict lower limb biomechanics, it is unclear how trained adaptations of muscular activation patterns are related to lower limb joint kinematics and kinetics during a single-leg land and cut maneuver. With that in mind, the purpose of this study was to identify and then compare the relation between training-induced changes in explicit lower limb neuromuscular control strategies and joint biomechanics elicited during unilateral landings following isolated core stability/balance, plyometric, standard neuromuscular and no training programs. Specifically, this study examines the extent to which core stability/balance and plyometric training, when used as single training modalities, produce neuromuscular control adaptations that associate with concomitant reductions in high-risk lower limb landing biomechanics. We hypothesize that for all training (core stability and balance, plyometric and standard neuromuscular), but not the no training group, higher levels of hamstring activation and hamstring to quadriceps co-contraction ratio will significantly predict higher peak stance hip and knee flexion angle, and lower peak stance hip and knee moment and anterior knee joint reaction force following training. For only the plyometric and standard neuromuscular participants, however, decreased levels of vastus lateralis, and increased lateral hamstrings activation and lateral hamstring to vastus lateralis co-contraction ratio will predict a concomitant reduction in peak stance knee abduction angle and moment following training compared to the no training and core stability/balance groups. Finally, for both the core stability/balance and standard neuromuscular participants, increased levels of gluteus medius activation will significantly predict a reduction in peak stance hip adduction angle and moment following training compared to the control and plyometric participants.

METHODS

Subjects:

A power analysis of our preliminary data comparing sagittal knee kinetics with three thigh muscle activity (rectus femoris, vastus lateralis and lateral hamstring) predictors indicated 26 subjects were needed to achieve 80% statistical power with an alpha level of 0.05. Thus, we over recruited with 56 participants (43 Training and 13 No Training). Subjects were currently on organized athletic teams participating in high-risk activities (e.g. basketball, field hockey, soccer, and volleyball). If potential subjects had: (1) a history of previous knee injury or surgery, (2) pain in lower extremity prior to testing or training, (3) any recent injury to the lower extremity (previous 6 months), and/or (4) were currently pregnant they were excluded from the study. The University Institutional Review Board gave research approval and written consent was obtained from all participants before testing. Also, leg dominance, defined as the leg which they could kick a ball the furthest[138], was assessed from prior to testing. During all data collections, subjects wore spandex shorts and their own athletic shoes

Study Procedures

All subjects were required to complete two testing sessions. The testing sessions occurred prior to and immediately following a six-week neuromuscular training program. All eligible participants were randomly allocated into one of four groups (Group 1: standard neuromuscular, Group 2: core stability and balance, Group 3: plyometric and Group 4: no training) following the initial, baseline testing session. The second and final testing session occurred immediately following (within two days) the six-week training protocols, or after six-week break for the no training group.

The training programs consisted of either a 60-minute standard neuromuscular (NM) (Figure 3.1) or 30-minute isolated component protocol core stability and balance (CORE), or plyometrics (PLYO) (Figure 4.1). Further specifics (e.g exercises and program goals) of all neuromuscular training programs were previously presented in detail (Brown, AIM 3). Each training program was comprised of three weekly sessions for a total of 18 sessions during the six-week period. To successfully complete the training program and be included in the final analysis each subject was required to participate in at least 16 of the 18 possible sessions.[99, 158] The no training group (CON) did not receive any neuromuscular training during the six-week training period and were asked to continue their normal daily activities during that time period.

Neuromechanical Testing

Subjects had synchronous bilateral three dimensional (3D) lower limb (hip, knee and ankle) joint kinetic and kinematic data recorded during a series of unilateral landings. During the unilateral landing task, the subject started in a standing posture at a distance equal to the length of their dominant limb from the front edge of the force platform. The jump landing required the subject to clear a 17 cm box before performing one of two (L1 or L2) pre-defined, randomly ordered landings.[31, 34] As previously reported[34], L1 required the subjects to jump forward, land only on their left foot and then aggressively jump laterally to the right (Figure 2.1). For L2, subjects jumped forward, landed on their right foot and immediately jumped laterally to the left. Subjects performed the jump landing protocol until five successful trials of each condition (L1 and L2) were recorded.

Biomechanical Analyses

For all jump landings, eight high-speed (240 fps) optical cameras (MX-13, Vicon, Lake Forest, CA) recorded the 3D coordinates of thirty-one (14 mm diameter) precisely attached reflective skin markers (Figure 2.2)[31] while synchronous ground reaction force (GRF) data was captured via two force platforms (AMTI OR6, Advanced Mechanical Technology Inc., Watertown, MA) embedded in the floor. Lower extremity joint rotations were quantified for all jump landings based on the marker coordinate data. Markers were attached and secured by a single experimenter (TNB) to pre-determined anatomical landmarks via double-sided tape and hypoallergenic, air-permeable cross elastic tape (Cover-Roll Stretch, BSN medical GmbH, Hamburg, Germany). To prevent excessive movement during landing attachment of markers over areas of large muscle/tissue mass was avoided.

Following marker placement, the subject stood in a stationary (neutral) position while a high-speed video recording was taken. From the stationary recording, Visual 3D v4.00 software (C-Motion, Rockville, MD) was used to create a kinematic model comprised of seven skeletal segments (bilateral foot, shank and thigh segments and the pelvis) with 24 degrees of freedom. In the kinematic model, the pelvis was defined with respect to the global (laboratory) coordinate system and assigned six (three translational and three rotational) degrees of freedom.[138, 139, 242] Hip[20], knee[83, 228], and ankle[242] joint centers and associated orthogonal local segment (3 degrees of freedom) coordinate systems were defined in accordance with previous literature and our own previous work.[20, 83, 228, 242]

During each jump landing, synchronous 3D GRF data was collected at 1200 Hz, and along with 3D marker trajectories were low pass filtered with a fourth-order Butterworth filter at a cut-off frequency of 12 Hz.[34, 142] Visual 3D software was used to solve the recorded 3D marker trajectories recorded during each jump landing trial for the lower limb joint rotations at each time frame. Resultant hip, knee and ankle joint rotations were expressed relative to the subject's static (neutral) 3D posture.[110, 134, 138] The filtered kinematic and GRF data were processed using conventional inverse dynamics analyses to obtain 3D intersegmental forces and moments at each lower limb joint.[235] The segmental inertial properties were defined in accordance with the work of Dempster.[57] Hip, knee and ankle 3D intersegmental forces were transformed to respective distal segment reference frames (femoral, tibial and talar) and anterior-posterior, medial-lateral and compression-distraction forces were calculated. The resultant intersegmental moments at the hip and knee were characterized as flexion-extension, abduction-adduction and internal-external rotation moments with respect to the cardanic axes of their respective joint coordinate systems.[138, 139] Similar to the kinematic data, intersegmental ankle moments were expressed as plantar-dorsiflexion, internal-external rotation, and supination-pronation. All kinetic variables were normalized to participant body mass (kg) and height (m). The kinematic and kinetic data were time-normalized to 100% of stance (heel strike to toe-off) and re-sampled at 1% increments (N = 101) with heel strike and toe-off defined as the instant GRF first fell below and exceeded 10 N, respectively [31].

Electromyography Analysis

During the landing protocol, subjects had lower extremity muscle activity recorded using surface electromyography (EMG) electrodes with 10 mm inter-electrode distance. The EMG data was recorded at 1200 hertz with a 16 channel EMG system (Delsys, Boston, MA) that was synchronized with the force platforms via the motion capture system (MX-13, Vicon, Lake Forest, CA). The EMG electrodes were placed over the muscle bellies of the lateral hamstrings (LH), vastus lateralis (VL), rectus femoris (RF) and gluteus medius (GM) muscles according to the guidelines of Delagi[54] during all landings. To secure the electrodes, hypoallergenic, air-permeable cross elastic tape (Cover-Roll Stretch, BSN medical GmbH, Hamburg, Germany) was used and were further secured with either spandex shorts or cohesive athletic tape (Powerflex, Andover Healthcare, Inc., Salisbury, MA).

Prior to the landing protocol, EMG data was recorded during a two-second maximal voluntary isometric contraction (MVIC) for knee flexion and extension, and hip abduction, respectively. Subjects performed the knee flexion and extension MVICs seated with their hip and knee angle maintained at approximately 90° and 45°, while for the hip abduction MVIC the subjects stood in a neutral position holding on to a chair placed in front of them. During all MVICs, the subjects were instructed to perform a maximal contraction into the resistance of the examiner.

The EMG data, both dynamic and MVIC, was band-pass (10 – 500 Hz) filtered with a fourth order, zero lag Butterworth filter to attenuate movement artifacts before subsequent processing with a 50-millisecond root mean square (RMS) moving window. The dynamic EMG data were then normalized to the MVIC activity of the respective muscle (i.e. quadriceps during the knee extension, hamstrings during knee flexion, and gluteus medius during hip abduction) before collecting the average RMS activity during the pre-activity (100 ms prior to ground contact) phase. Furthermore, simultaneous RMS activation of the vastus lateralis and lateral hamstrings (VL:LH) during the pre-activity phase was used to calculate a muscle co-contraction ratio with a formula previously reported by Rudolph et al. [193]:

Statistical Analysis:

Subject-based mean values of each average RMS pre-activity variable was submitted to a two-way ANOVA to test for the main effects of and possible interactions between training group (NM, CORE, PLYO and CON) and testing time (pre- and post-training). In instances where statistically significant differences between testing time and training group, as well as, a significant testing time by training group interaction were observed, Bonferroni pairwise comparisons were used. Prior to statistical analysis, training changes were calculated for all EMG and biomechanical variables. Specifically, the average pre-training RMS activity of the LH, VL, RF and GM, and VL:LH were subtracted from the post-training values, while pre-training values of peak stance hip and knee flexion-extension and abduction-adduction angles and moments, and peak anterior knee joint reaction force were subtracted from their respective post-training values to obtain a training change score. Then multiple stepwise regressions were fit using SPSS (18.0, SPSS Inc., Chicago, IL) to determine the association of the pre-post change of the pre-activity of VL, LH and VL:LH with peak knee flexion and abduction angle and moment, while VL, LH and RF was submitted to assess the relationship with anterior knee joint reaction force. The change score of the pre-activity of RF, LH and GM were used to assess their relationship with hip flexion and adduction angle and moment, respectively. All regression analyses were run stratified by each training group (NM, CORE, PLYO and CON). An alpha level of 0.05 was selected to determine if predictor variables would be included in the final equation and for determining the significance of the model in predicting the response variable.

RESULTS

The final statistical analysis included forty-three subjects (Table 4.1), as 13 subjects were excluded from the final analysis. The excluded subjects did not complete an adequate amount of training or the second testing session within the required time frame after the training period. The training changes (post-training- pre-training values) in pre-activity EMG parameters are presented in Table 5.1. The ANOVA revealed a significant interaction ($p = 0.038$) for lateral hamstrings pre-activity. Specifically, the NM training group ($p = 0.024$) displayed a substantial decrease in lateral hamstrings preparatory activation following the six-week training period, whereas, no significant differences were evident for the CORE ($p = 0.209$), PLYO ($p = 0.097$) or CON ($p = 0.911$) groups following training. Furthermore, there was a significant main effect of testing time for vastus lateralis ($p = 0.021$) and rectus femoris ($p = 0.011$) activation with a substantial decrease in activity at the post-training compared to the pre-training time point for both muscles. No significant differences ($p > 0.05$), however, were evident between testing sessions for any other EMG pre-activation parameter.

Table 5.1 Average change (post-training – pre-training) in RMS activation (mean ± SD) of the dominant limb following neuromuscular training for the pre-activity phase of the single-legged landing maneuver.

Variable	Pre-activity (% of MVIC)				
	Total	**NM**	**CORE**	**PLYO**	**CON**
Vastus Lateralis (VL)*	-28.1 ± 69.2	-15.9 ± 49.0	-13.5 ± 47.9	-10.5 ± 48.6	-63.0 ± 97.9
Rectus Femoris (RF)*	-8.8 ± 19.0	-12.4 ± 19.0	-11.8 ± 23.2	1.8 ± 12.1	-15.1 ± 20.0
Lateral Hamstring (LH)#	-2.5 ± 20.2	-14.0 ± 23.1	-9.1 ± 22.1	9.7 ± 18.6	-0.6 ± 12.5
Gluteus Medius (GM)	2.1 ± 40.0	-19.0 ± 27.4	-12.6 ± 30.7	11.2 ± 43.6	19.2 ± 42.7
VL:LH	-2.54 ± 30.33	-19.25 ± 36.67	-12.52 ± 33.05	14.06 ± 25.97	1.63 ± 19.67

* significant difference between training group
# significant difference between testing time and training group

Peak stance (0 – 50 %) phase hip and knee joint biomechanical data elicited during the single-legged landing task at both the pre-training and post-training time points for all groups are presented in Figure 5.1 and 5.2. The training changes in peak stance phase hip flexion and adduction angles were 1.36 ± 6.93° and -1.13 ± 6.87°, respectively, while changes in mean peak stance hip flexion and adduction moments were 0.01 ± 0.24 N/kg/m and 0.00 ± 0.21 N/kg/m, respectively. Peak stance knee flexion and abduction angles changed by 0.25 ± 6.71° and -0.43 ± 2.78°, while knee flexion and abduction moments changed by 0.04 ± 0.23 N/kg/m and -0.04 ± 0.15 N/kg/m following training. Finally, the mean change in normalized peak anterior knee joint reaction force during the single-legged maneuver was 0.02 ± 0.69 N/kg of BM.

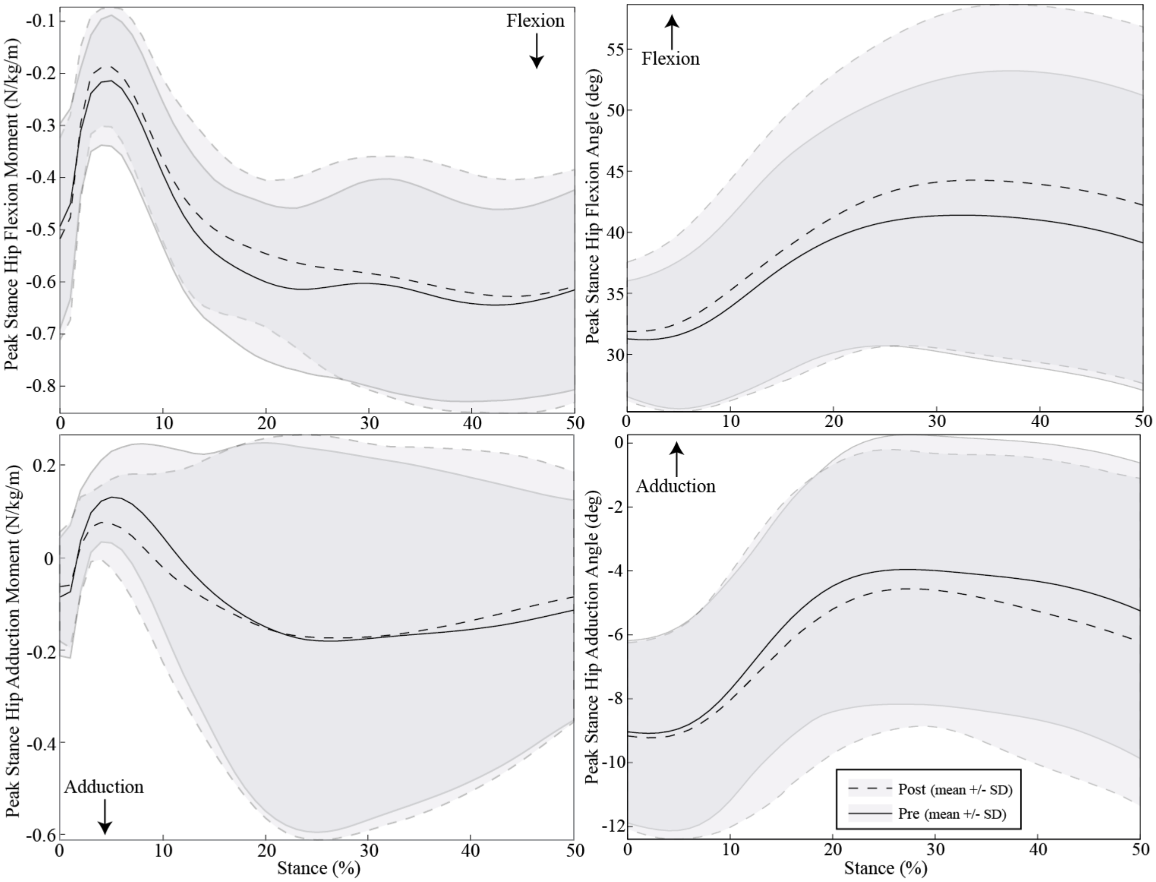


Figure 5.1 Mean (± SD) stance phase hip biomechanical patterns during the single-legged landing maneuver at both the post and pre-training time points. Stance phase patterns for hip flexion and adduction angle and moment are presented.

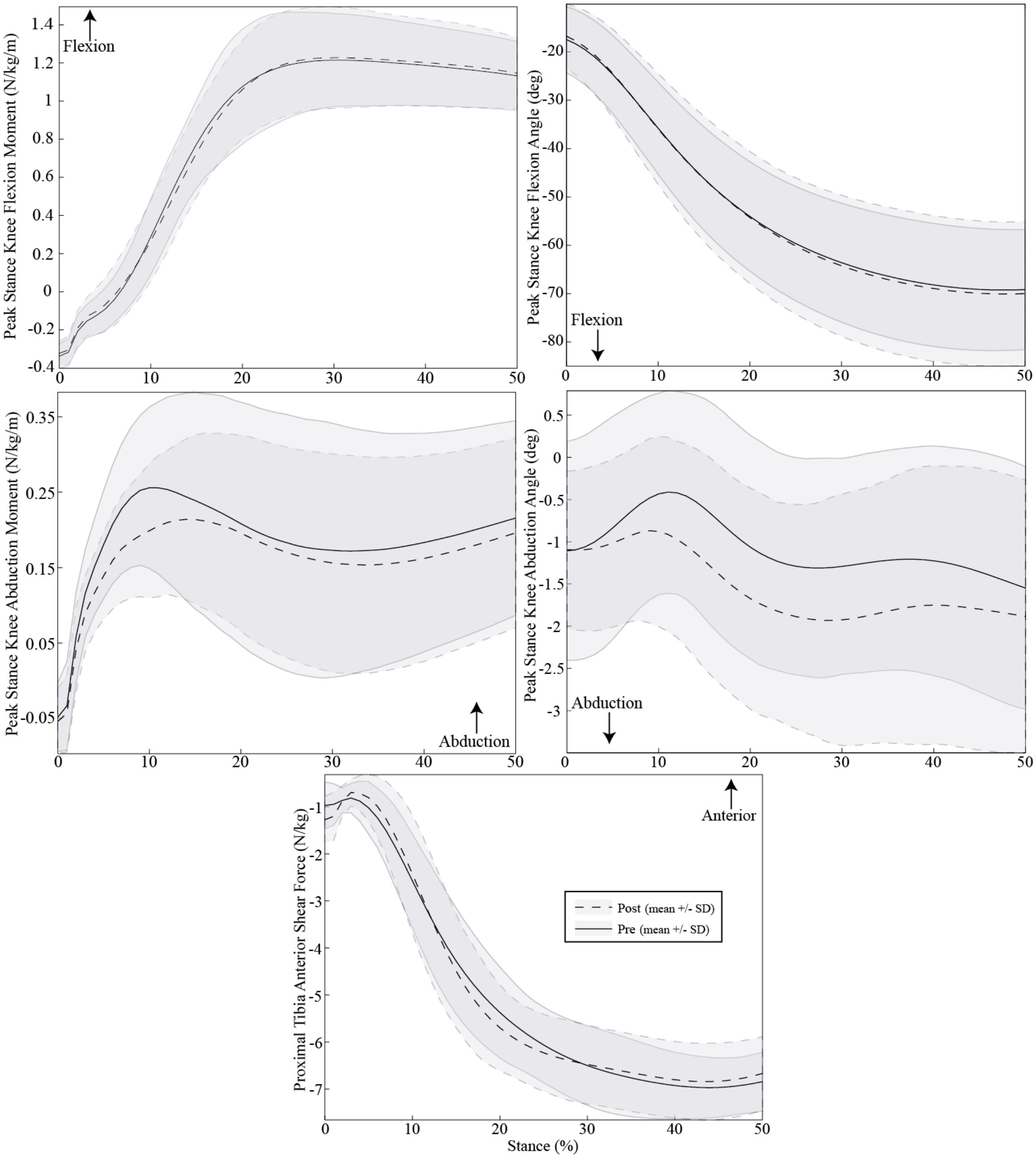


Figure 5.2 Mean (± SD) stance phase knee biomechanical patterns during the single-legged landing maneuver at both the post and pre-training time points. Stance phase patterns for anterior knee joint reaction force, and knee flexion and abduction angle and moment are presented.

Significant associations were identified for pre to post-training changes in preparatory EMG variables with trained modifications in knee biomechanics for the NM, CORE and CON groups. For the NM group, preparatory activation of the lateral hamstrings was found to be a significant predictor of peak anterior knee joint reaction force ($R^2 = 0.616$, *b*

= 2.814 and *P* = 0.007) (Figure 5.3 and Table 5.2). Specifically, a 10 % increase in preparatory lateral hamstrings activity (% of MVIC) following NM training predicted a 2.81 N/kg increase in anterior reaction force, when holding the other predictors constant. Preparatory vastus lateralis activation was identified as a significant predictor of peak stance knee abduction angle (R^2 = 0.508, *b* = 1.540 and P = 0.006) for the CON participants (Figure 5.4 and Table 5.3). Specifically, a 10 % increase in vastus lateralis activity (% of MVIC) predicted a 1.54° decrease in peak knee abduction angle, when the other predictors were held constant. For the CORE participants, the VL:LH co-contraction ratio explained a significant portion of the variance in peak stance knee abduction angle (R^2 = 0.685, *b* = -0.091 and P = 0.022) (Figure 5.5 and Table 5.3). Here, a 10 % decrease in VL:LH co-contraction (% of MVIC) predicted a 0.91° decrease in peak knee abduction angle, when the other predictors were held constant. No preparatory EMG activation parameters, however, were identified as significant predictors (P > 0.05) for peak stance knee flexion and abduction moment, or knee flexion angle.

Table 5.2 Regression coefficients from the full stepwise regression models associating pre-post changes in preparatory muscle activation variables with training changes in peak stance (0%–50%) phase anterior knee joint reaction force.

Variable	**Anterior Reaction Force**		
	NM		
	β	**t**	**P**
VL	0.051	0.217	0.834
RF	0.356	1.464	0.186
LH	2.814	3.582	0.007*

* Denotes partial regression coefficient is statistically significant

Table 5.3 Regression coefficients from the full stepwise regression models associating pre-post changes in preparatory muscle activation variables with training changes in peak stance (0%–50%) phase knee abduction angle.

Variable	**Knee Abduction Angle**					
	CORE			**CON**		
	β	**t**	**P**	**β**	**t**	**P**
VL	0.262	0.986	0.380	1.540	3.372	0.006*
LH	1.170	1.035	0.359	0.132	0.607	0.557
VL:LH	-0.091	-3.297	0.022*	0.135	0.608	0.557

* Denotes partial regression coefficient is statistically significant

Significant associations were identified for pre to post-training changes in preparatory EMG variables with trained modifications in hip flexion moment for NM and PLYO groups. For the NM group, lateral hamstrings pre-activity significantly predicted peak stance phase hip flexion moment ($R^2 = 0.484$, $b = -0.742$ and $P = 0.025$) (Figure 5.3 and Table 5.4). Specifically, a 10% increase in lateral hamstring pre-activity (% of MVIC) following training predicted a 0.74 N/kg/m increase in hip flexion moment, when holding the other predictors constant. Rectus femoris preparatory activity, however, explained a significant portion of the variance in peak stance hip flexion moment ($R^2 = 0.447$, $b = -1.246$ and $P = 0.049$) for the PLYO participants (Figure 5.6 and Table 5.4). Specifically when holding other predictors constant, a 10 % increase in rectus femoris pre-activity (% of MVIC) following training predicted a 1.25 N/kg/m increase in hip flexion moment. Finally, no preparatory EMG activation parameters, however, were identified as significant predictors ($P > 0.05$) for peak stance hip flexion and adduction angle or adduction moment.

Table 5.4 Regression coefficients from the full stepwise regression models associating pre-post changes in preparatory muscle activation variables with training changes in peak stance (0%–50%) phase hip flexion moment.

Variable	**Hip Flexion Moment**					
	NM			**PLYO**		
	β	**t**	**P**	**β**	**t**	**P**
RF	-0.137	-0.431	0.679	-1.246	-0.669	0..049*
LH	-0.742	-2.742	0.025*	-0.287	-0.941	0.383
GM	-0.146	-0.522	0.618	-0.258	-0.904	0.401

* Denotes partial regression coefficient is statistically significant.

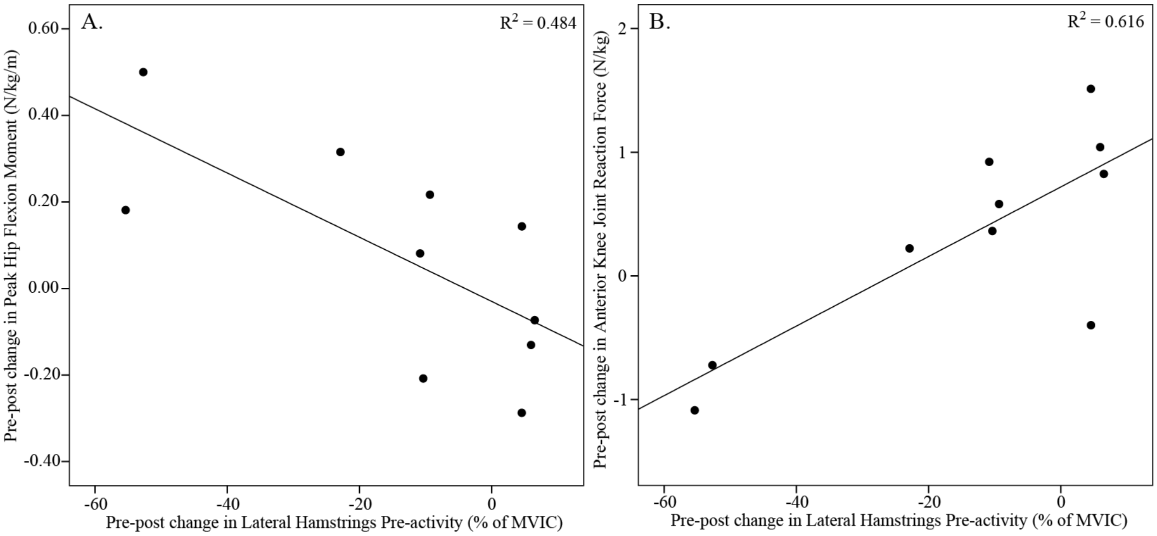


Figure 5.3. Relation between pre-post change in lateral hamstrings pre-activity with peak stance hip flexion moment (**A**) and peak anterior knee joint reaction force (**B**) during single-legged landings for the NM group.

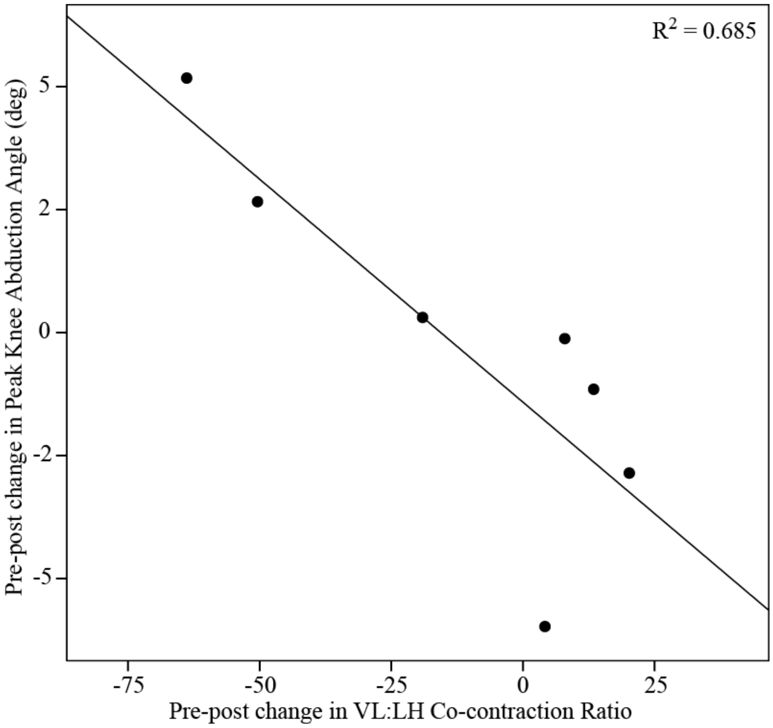


Figure 5.4. Relation between pre-post change in peak stance knee abduction angle with VL:LH co-contraction ratio for the CORE group.

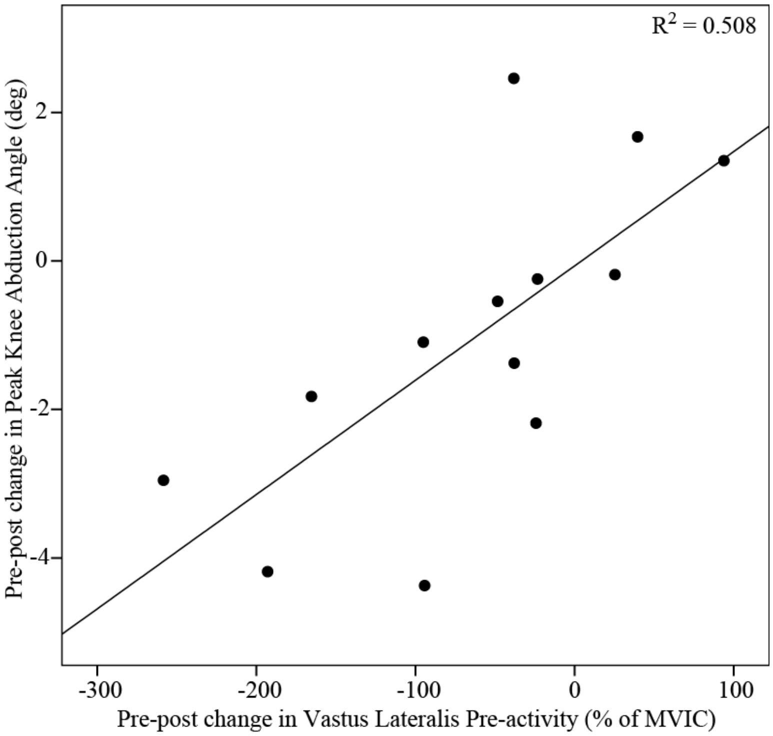


Figure 5.5. Relation between pre-post change in peak stance knee abduction angle with vastus lateralis pre-activity for the CON group.

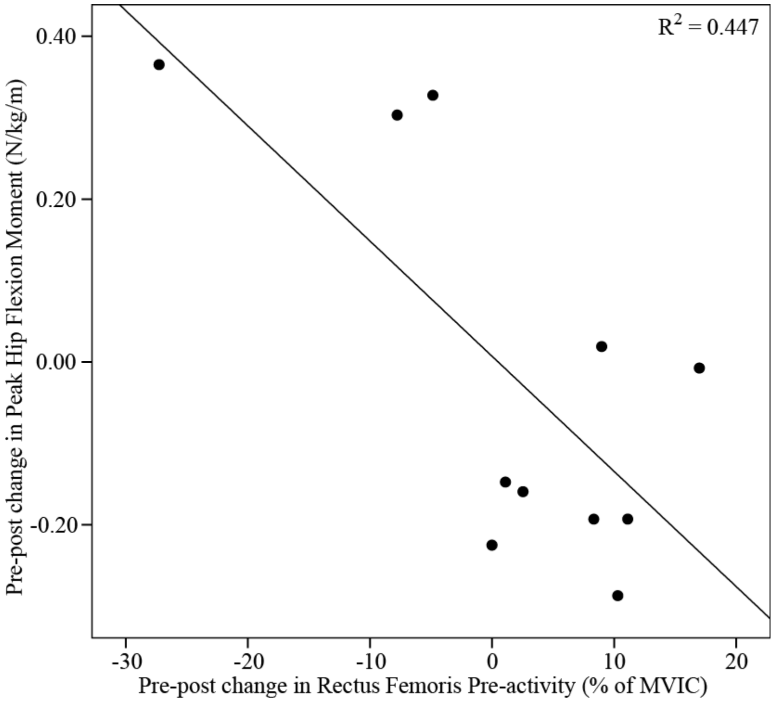


Figure 5.6. Relation between pre-post change in peak stance hip flexion moment with rectus femoris pre-activity for the PLYO group.

DISCUSSION

Specific neuromuscular control strategies have been suggested to predict explicit "high-risk" lower limb landing biomechanics.[172, 173] To date, however, it is unclear which neuromuscular adaptations predict modifications in lower limb joint kinematics and kinetics following training. It also remains unclear whether isolated core stability or plyometric training can promote neuromechanical adaptations. Thus, the purpose of this study was to compare the relation between training-induced changes in explicit lower limb neuromuscular control parameters and joint biomechanics elicited during unilateral landings following isolated core stability/balance, plyometric, standard neuromuscular and no training programs. Current outcomes demonstrate trained changes thigh muscle activation strategies may be critical to the execution of a safe lower limb joint biomechanical profile, particularly during a unilateral landing task.

Prior to training, we hypothesized that for all training (NM, CORE and PLYO) groups, increased hamstring activation and hamstring to quadriceps co-contraction ratio would significantly predict hip and knee sagittal plane biomechanical adaptations during landing. Only the NM group exhibited changes of preparatory hamstrings activation patterns that predicted concomitant modifications in lower limb sagittal plane hip moments. Specifically during the unilateral landing, a trained increase in the pre-activity of the lateral hamstrings predicted a larger peak hip flexion moment between the pre- and post-training time points for the NM group. Shimokochi et al.[208] previously concluded that an increased hip flexion moment would place greater demand on the hamstrings musculature during landing, thereby, reducing quadriceps activation. The current outcomes support this observation and suggest greater hamstring activation may reduce sagittal plane loading of the knee joint. It may be neuromuscular-based training improves hamstrings control and thus its support of the center of mass during landing. Following training, the bi-articular hamstring musculature may provide greater support of the control of the center of mass as it is passed down the kinetic chain during the loading phase of a jump landing. This improved support may reduce the load placed on the quadriceps, coinciding with reduced quadriceps activation, which we in fact saw in the current outcomes. This substantial reduction of quadriceps activation may subsequently promote a “safer” knee neuromechancial profile through a reduction in knee flexion moment.

We had predicted that changes in quadriceps activation prior to training would have no significant association with adaptations of sagittal plane biomechanics. Contrary to our hypothesis, however, the PLYO group demonstrated a significant association between rectus femoris activation and peak hip flexion moment. Plyometric training consists of dynamic, fast-paced landings, which only afford the trainer the opportunity to provide observational-based feedback at the conclusion of each exercise.[157] Thus, this requires the athlete to make a cognitive response to the feedback and apply it on subsequent exercise attempts. It may be this method of training allows the athlete greater cognitive awareness of the quadriceps musculature and thus improved eccentric control during landings, specifically at the hip.

Although, the coordinated contraction the quadriceps and hamstrings musculature plays a large role in regulating muscle stiffness and joint stability[62, 230], it may not substantially impact the specific hip and knee sagittal plane kinematics during landing. Outcomes of the current study are in agreement with previous findings by Shultz et al.[213], who concluded that lower limb muscle activation strategies are not strong predictors of sagittal plane hip and knee posture. This outcome fails to provide a direct link to successfully increase both peak hip and knee flexion during landing, which is a stated benefit of the current prevention model. Despite the significant link between neuromuscular control and lower limb sagittal plane kinematics, previous prevention literature purports hip and knee flexion posture are modifiable characteristics of a lower limb neuromechancial profile. It may be joint excursions up and down the kinetic chain, i.e. greater hip and ankle flexion, drive modification of sagittal knee posture, and not quadriceps and hamstrings activation patterns.

We hypothesized that increased hamstrings activation during the single-leg landings would predict reduced peak anterior knee joint reaction forces following training. This relation was not currently evident. Despite the fact that increased hamstring activation purportedly creates a posterior shear force at the knee that may stabilize the joint and decrease ACL strain.[59, 130, 190, 238] In fact for the NM group, a reduction in anterior joint reaction force was predicted via a trained decrease in lateral hamstrings activation. The reason for this counterintuitive observation, and for the fact it only presented in the NM group, is not immediately clear. The smaller amplitude of lateral hamstrings activity evident in the NM group following training, which contradicts previous outcomes[231], may translate into a reduction of ligament strain during single-legged landings. It may be, this training modification that stems from an integrated, i.e. combination of two or components, training protocol. Neither of the isolated (CORE and PLYO), or the no training (CON) groups displayed a substantial change of hamstrings activation following the six-week training period. The NM participants, who were exposed to a larger volume and duration of training, may have had greater training modifications. A potential modification of the NM group might be a more selective muscular activation strategy, i.e. reduced hamstrings activation. This reduction in hamstrings activity may coincide with knee joint biomechanical changes during unilateral landings, i.e. increased knee flexion, not present for the other training groups. (Brown, AIM 3)

Current outcomes demonstrate that explicit lower limb neuromuscular control variables predict sagittal plane loading, but do not appear to have a significant relation with lower limb sagittal plane kinematics. Conversely, trained muscle activation strategy adaptations predict concomitant modifications of frontal plane knee joint motions, but not loads. Specifically for the CON group, greater vastus lateralis pre-activity following training predicted a decreased peak stance knee abduction angle. These findings are in agreement with previous work demonstrating similar links between vastus lateralis pre-activity and knee abduction motion.[173] The direction of the current relation between quadriceps activation and knee abduction angle, however, contradicts previous evidence. Previous experimental evidence suggested a decrease in vastus lateralis preparatory activity may coincide with a reduction in peak stance knee abduction angle. For the CORE group, however, training induced increases of the vastus lateralis to lateral hamstring co-contraction ratio were associated with peak knee abduction angle. It may be that the simultaneous feedback that occurs during the balance and stabilization tasks of the CORE training allows the athlete to make conscious alterations of muscle activation patterns that reduce hazardous knee postures, i.e. excessive knee abduction angle. While the CON group may have altered their neuromuscular control strategies due to repeated exposure to the testing protocol. Specifically, they may have developed a generalized contraction strategy with larger amplitudes of preparatory quadriceps activation that was used to increase muscle stiffness during the loading phase of landing. The improved muscles stiffness of the CON group may have coincided with a reduction of peak knee abduction angle. This neuromuscular adaptation may have not been present in the NM, CORE and PLYO groups because of the refined activation strategies that result with the performance of a neuromuscular-based injury prevention programs. Regardless, limiting knee abduction posture may be essential to reducing the non-contact ACL injury rate as it has been prospectively linked to injury risk[95] and may produce the largest amount of ACL strain when combined with proximal tibia anterior shear force.[24] To date, however, reduced knee abduction posture during single-legged landings has not been demonstrated following injury prevention protocols. Further work is needed to determine whether the balance and stabilization tasks of CORE training can produce neuromuscular control adaptations that decrease knee abduction posture and subsequent ACL loading during single-leg maneuvers.

We hypothesized that training protocols containing plyometric exercises (NM and PLYO) would exhibit a trained reduction of vastus lateralis, and increased lateral hamstrings activation and lateral hamstring to vastus lateralis co-contraction ratio, predicting reduced peak stance knee abduction angles and moments. Interestingly for neither NM nor PLYO groups were preparatory quadriceps or hamstring activation parameters identified as predictors of knee frontal plane biomechanics. This observation contradicts previous work by Palmieri-Smith et al.,[172] who identified quadriceps to hamstrings co-contraction ratio as a predictor of peak knee abduction moment in females during a single-leg forward hop. This discrepancy may stem from the time period when muscle activity was analyzed. Previously, Palmieri-Smith calculated the association between frontal plane knee joint loading and quadriceps to hamstrings co-contraction ratio over the reactive, loading phase of the jump landing. The current study, however, examined the relation between preparatory (100 ms prior to ground contact) muscle activation and peak knee abduction moment. Reactive patterns, which may aid in increasing muscle stiffness following landing, might have insufficient time to prevent injurious loading patterns. Thus, targeted modification of reactive muscle activation patterns might not have the potential to reduce ACL injury risk and are not an ideal platform for future injury prevention efforts to target. Preparatory muscle activity, however, is purported to play an important role in dynamic joint stability[62, 230], making it a better target for injury prevention programs. Further considering, the quadriceps and hamstrings musculature have moment arms that support knee abduction/adduction torques[250], they may have the potential to reduce peak frontal plane loading. The current outcomes do not support this theory, but was previously demonstrated in male athletes.[26] Specifically, Besier et al.[26] concluded that preparatory activation patterns were evident during sidestepping tasks as a means to support and potentially resist knee abduction loads. Thus, further insight into the links between quadriceps and hamstrings muscle activation strategies, and frontal plane knee motions and loads are necessary, especially for female athletes. Such work seems critical considering the touted link between these biomechanical parameters and ACL injury risk.[95]

The current outcomes do not support the hypothesis that improved gluteus medius activation would result in concomitant reduction peak hip adduction posture and load. Reducing hip adduction posture may be an important training modification, as greater adduction may translate to increased dynamic knee valgus and ACL load.[46, 234] Previously, it has been suggested that gluteus medius weakness may predispose an athlete to greater hip adduction during landing[105, 188], but this association has not been consistent across all studies.[233] We did not currently identify preparatory gluteus medius activation as a strong predictor of hip adduction motions or loads. It may be hip abductor, i.e. gluteus medius, control accounts for a small, insignificant portion of the change in the abduction posture. Willson et al.[233] previously reported that despite an increase of hip abduction strength, no meaningful change in hip frontal plane kinematics was evident during single-legged jump landings. Therefore, it may be that trained adaptations of gluteus medius strength and activation are insufficient to produce substantial alterations of frontal plane hip biomechanics. It may be, however, that female frontal plane loads are particularly sensitive to hip posture[139], which does not exhibit significant training modifications because there is a relatively small window of “safe” angles. Regardless, controlling frontal plane hip biomechanics may be an important factor to decreasing the non-contact ACL injury rate and future work is warranted to determine specific neuromechanical factors that predict a reduction of out of plane hip motions and loads.

The purpose of this study was to compare trained adaptations of neuromuscular control strategies with concomitant modifications of lower limb landing biomechanics between different ACL injury prevention protocols. Neuromuscular control strategies, which regulate muscle stiffness and provide dynamic joint stability, may have explicit activation patterns that coincide with specific lower limb biomechanics. If this were the case then trained biomechanical adaptations may be predicted by modification of an explicit muscular activation pattern and linked to a particular training modality. Specifically, both the NM and PLYO groups had trained modifications that predicted improved hip sagittal plane loading, whereas, the CORE group produced adaptations that decreased frontal plane knee motion. If these explicit sagittal and frontal plane biomechanical factors do, indeed, dictate injury risk, then the current outcomes suggest both PLYO and CORE training warrant inclusion in future injury prevention efforts. In fact, it may be, future neuromuscular-based ACL injury prevention programs can be composed of just CORE and PLYO exercises to promote “safer” lower limb neuromechanical profiles. Further work is needed to test such tenet and to ensure prevention efforts are addressing the true biomechanical injury predictors.

Conclusion

In conclusion, ACL injury prevention programs may promote training adaptations of neuromuscular control strategies that are related to concomitant modifications of lower limb landing biomechanics during single-legged landings. The current outcomes suggest trained improvements of quadriceps and hamstring activation may predict changes of sagittal plane loading, but not sagittal plane kinematics of the lower limb. To promote these lower limb sagittal plane modifications, which coincide with a “safer” knee neuromechanical profile, future injury prevention programs may need to include plyometric exercises. Training modifications of quadriceps and hamstrings activation may also predict changes of frontal plane motions, but not frontal plane loading of the lower limb. It may be core stability and balance training warrants inclusion in neuromuscular-based training programs as a means to produce adaptations of lower limb muscular activation patterns that predict concomitant reductions in hazardous frontal plane knee motions. Thus, it appears future injury prevention efforts are warranted to include exercises that promote adaptations of hamstrings and quadriceps activation to target biomechanical modifications that improve ACL loading. Specifically, it may be necessary for future injury prevention programs to include CORE and PLYO exercises to promote “safer” lower limb neuromechanical profiles. Further research is needed, however, to ensure training adaptations of neuromuscular control strategies are targeting modifications in lower limb biomechanics that are “true” predictors of injury risk.

CHAPTER 6

Discussion

The intent of this dissertation was to assess the effectiveness of the current ACL injury prevention platform and, in turn, use the acquired knowledge to improve the future prevention model. Current ACL injury prevention programs are purported to promote successful neuromechanical modifications through successful adaptations of both lower limb neuromuscular control strategies[231, 249] and/or joint biomechanics.[44, 90, 158] Although, neuromuscular control strategies are suggested to govern subsequent lower limb biomechanics, there is limited insight into the relationship between these two factors, especially during a unilateral landing. Promoting a “safer” lower limb neuromechanical profile during unilateral landings may be important as they have been implicated in the non-contact ACL injury scenario.[29, 100 167] Thus, the first step to improving the current prevention model would be to develop an understanding of the specific muscles groups to target within prevention programs to obtain a reduction of “high-risk” lower limb biomechanics.

In the first study, the relation between explicit preparatory lower limb neuromuscular control strategies and knee joint biomechanics was examined during execution of a single-legged land and cut maneuver. It was hypothesized that greater quadriceps activation would predict larger peak stance knee flexion moment, knee abduction angle and moment, and anterior knee joint reaction force. Greater hamstrings activation, however, was hypothesized to reduce knee flexion moment and anterior knee joint reaction force, as well as, increase peak knee flexion angle. Interestingly during the unilateral landings, quadriceps activation patterns were significantly associated with high-risk knee joint biomechanical profiles, whereas, there was no significant relationship between hamstrings activation and knee joint biomechanics. Specifically, greater rectus femoris activity was associated with increased peak anterior knee joint reaction force and increased vastus lateralis activation predicted greater peak knee flexion moment during the unilateral jump landings. These findings highlight a potential need for reduction of quadriceps activation patterns during unilateral landings. Thus, the future injury prevention model should consider reducing the reliance on quadriceps activity to provide adequate knee stability during dynamic movements, as a means to reduce injury risk.

Equally critical to improving the current prevention model is knowledge of whether trained biomechanical adaptations are attainable during unilateral landings. Currently, assessment of ACL injury prevention efforts has been based on simplistic, bilateral landings.[157] Little is known, however, regarding whether adaptations are possible for single-legged landings[157], despite the fact that they comprise approximately 70% of actual sports landings[222] and have been identified in the non-contact ACL injury mechanism.[29, 100 167] Elucidating the ability of current prevention strategies to achieve lower limb biomechanical adaptations during a unilateral landing provides a critical step to improve the effectiveness of the current training model.

For the second study, lower limb biomechanical adaptations were compared between bilateral and unilateral jumps landings after a standard six-week neuromuscular training program. This is an important step, as to date no one has determined if trained biomechanical adaptations evident during bilateral landings following training are similarly evident for unilateral landings. It was hypothesized that at the conclusion of training, subjects would demonstrate significantly greater improvements in hip and knee flexion angle, and reductions in hip adduction and knee abduction posture during the bilateral as compared to the unilateral landings. Following the injury prevention program, the training group demonstrated greater peak stance knee flexion posture during bilateral landings as compared to the no training participants. Similar differences of sagittal plane knee biomechanics, however, were not evidnet during unilateral landings. Furthermore, unilateral landings exhibited a substantially different lower limb landing biomechanical profile compared to the bilateral landings. It may be to promote modifications in unilateral landings future prevention efforts need to adapt the current training model. Currently, however, it is unclear which training exercises may potentially modify lower limb biomechanics during unilateral landings and thus would require inclusion in a future training program. This appears as a worthy target for future research efforts.

The current standard ACL injury prevention model is comprised of a series of specific training modalities (core stability/balance, plyometric, resistance, and speed).[95, 156, 159] Both core stability and plyometric components have been shown to have potential to modify lower limb biomechanics.[157] The precise adaptations via each component in isolation, however, are unclear and may be exercise specific. The current method, therefore, relies on successful training adaptations being obtained through an integrated training program (i.e. the combination of two or more training components).[171] As a result, current training methodologies are lengthy, hindering participant compliance.[160] The development of a shorter training protocol that produces the same trained modifications as the standard training protocol may combat these concerns, eventually reducing the non-contact ACL injury rate. Thus, testing training components, used in isolation, suggested to have potential to modify lower limb biomechanics is intuitive step to improve the current prevention model.

The purpose of the third study was to examine the extent to which core stability and plyometric components, used as a single modality, can modify “high-risk” landing biomechanics compared to the standard training and no training models. Understanding how, or if, specific injury prevention modalities work in isolation would facilitate the development of a more compact training model, which may combat the compliance issues that are a known limitation of current strategies.[160] It was hypothesized that prior to training, all training participants would improve sagittal plane hip and knee biomechanics, only plyometric and the standard program would improve frontal plane knee biomechanics, and only core stability and the standard model would improve frontal plane hip biomechanics after the six-week training period. Plyometric exercises used as a single modality were found to successfully modify sagittal plane knee and frontal plane hip and knee biomechanics. These substantial modifications following plyometric training, however, were only evident during bilateral landings. The standard neuromuscular training group demonstrated that current prevention model may, indeed offer the potential promote biomechanical adaptations during unilateral landings. It may be, therefore, that to promote biomechanical adaptations during unilateral landings, which present the greatest risk of ACL injury, a prevention protocol with a combination of two or more training components is required. Plyometric exercises may be an essential training modality to promote "safer" lower limb landing biomechanics, but may only modify lower limb biomechanics during unilateral landings when combined with another such components. Testing such tenets may be critical to developing an optimal training program.

Although, both the second and third studies assessed the effects of a standard neuromuscular program during both unilateral and bilateral jump landings. Their findings were contradictory. Specifically, it was noted during study two that lower limb landing biomechanical adaptations were not attained during unilateral landings, whereas, the standard neuromuscular training group of study three produced greater knee flexion posture during the unilateral landings at the conclusion at the six-week training period. A plausible explanation for the discrepancy was the study populations. The study two population consisted of recreational athletes who may possess an inconsistent movement strategy as a result of large variations in neuromuscular control and strength.[103, 141] Study three, however, used competitive athletes. It may be the competitive athletes are able to attain larger training modifications from their increased experience and more consistent movement strategies. [103, 141, 214] Thus, to improve the future prevention model, training programs may need to tailor strategies to participant skill and experience. Specifically, assessing the participant's age, athleticism, and level of competition prior to training may aid with maximizing potential training benefits, and should be considered in future prevention efforts.

Another avenue through which to maximize the potential of ACL injury prevention programs would be to target adaptations of explicit neuromuscular control parameters that counter “high-risk” biomechanical profiles. Currently, however, the effect of neuromuscular training on the relationship between these two factors is unknown. It also remains unclear whether isolated core stability or plyometric training can promote neuromuscular adaptations that coincide with beneficial modifications of lower limb biomechanics.

The purpose of the fourth and final study was to compare how training-induced changes in explicit lower limb neuromuscular control strategies predicted modifications of joint biomechanics elicited during unilateral landings following isolated core stability and balance, plyometric, standard neuromuscular and no training programs. It was hypothesized that for all training (core stability and balance, plyometric and standard neuromuscular) groups, increased hamstrings activation would significantly predict adaptations of lower limb sagittal plane biomechanics. Only for the plyometric and standard neuromuscular groups, however, would decreased levels of quadriceps and increased levels of hamstrings activation predict a concomitant reduction in frontal plane knee biomechanics. Further, only the core stability and balance, and standard neuromuscular groups, increased levels of gluteus medius activation would predict a reduction in frontal plane hip biomechanics. The current outcomes suggest both the standard neuromuscular and plyometric groups had trained modifications that predicted improved sagittal plane loading, whereas, the core stability group produced adaptations that decreased frontal plane knee motion. Future injury prevention efforts may be warranted to target adaptations of hamstrings and quadriceps activation as a means to produce biomechanical modifications that improve ACL loading. Specifically, plyometric training may produce adapatations of rectus femoris activity that improve lower limb sagittal plane loading, while core stability and balance training may produce modifications in the vasutus lateralis and lateral hamstring co-contraction ratio that coincide with a reduction in frontal plane knee motion. To promote a “safer” knee neuromechanical profile, therefore, future injury prevention programs may only need to be composed of core stability and plyometric exercises. Although, further research is needed to test such tenet and to ensure prevention programs are targeting modifications in lower limb biomechanics that are “true” predictors of injury risk.

Collectively, these studies provide a foundation for improving the current ACL injury prevention model. I have highlighted the need future prevention modalities to diminish the amplitude of quadriceps activation during single-legged landings to provide a reduction in injury risk. Future injury prevention efforts may focus on improving quadriceps strength and lower limb sagittal plane posture during landing to facilitate the reduction of quadriceps activation. Furthermore, targeting adaptations of hamstrings and quadriceps activation patterns appears warranted as a means to produce biomechanical modifications that improve ACL loading. To promote lower limb biomechanical adaptations during these risky, unilateral landings, however, future prevention modalities should combine two or more training components to maximize potential benefits. Specifically, it appears that inclusion of both core stability and balance, and plyometric exercises are necessary to promote a “safer” knee neuromechanical profile. I suggest, therefore, that the future injury prevention model should be composed of core stability and plyometric exercises. Potential benefits of neuromuscular-based training, however, may be dependent on not only the exercises preformed, but participant skill and experience, as well. To maximize potential benefits future injury prevention programs may need to assess the participants’ age, athleticism and level of competition prior to training. It may be younger and/or weaker participants require a resistance component or longer periods of training to promote neuromechanical modifications from an injury prevention protocol.

Going forward, I recommend that future prevention efforts utilize an integrated training protocol, consisting of both core stability and plyometric exercises. The future training model, however, should drastically shorten the training time of each session. Current training methods are lengthy, roughly 90 minutes a session, which limits participant compliance.[160] Hopefully, a shorter protocol using core stability and plyometric components would provide similar neuromechanical modifications as previous integrated prevention efforts, but improve program participation and effectiveness. A shorter protocol may allow for more coaches and teams to implement the prevention program, as well as, limit the number of athletes lost to disinterest. Finally, I would also extend the training period beyond six weeks, as may be needed to obtain beneficial muscular adaptations. During the early stages (weeks 1- 6) of training, adaptations of the neuromuscular system are dominated by neural factors (i.e. changes in types of contractile proteins), whereas, longer training periods (> 8 weeks) are need to modify hypertrophic factors (i.e. muscle protein increases) that contribute most to changes in performance capabilities. Thus, greater neuromuscular performance may result from increasing the training period of the future injury prevention model.

LIMITATIONS OF THE DISSERTATION

A possible limitation of the dissertation was the method of randomization. Specifically for studies three and four, the potential subjects were randomly allocated into the training groups by team. Although, this method of randomization may have introduced confounding into the study, it was necessary to accomplish the study. To ensure adequate subject numbers and to overcome the logistics of training study of this magnitude, potential subjects needed to be randomized to training group by team.

Another possible limitation of the dissertation was the fact the investigator was not blinded to the participants' group status. This may have introduced bias into the study. The lack of blinding may have resulted in the investigator influence during the data collections and possibly information bias. Although, it was currently not possible to blind the investigator from participant training status we believe you can interpret the findings with confidence.

Additionally, the measurements used in studies one and four for normalization of the muscle activation data during the dynamic landings were highly dependent on the subject eliciting maximal effort. Despite the best efforts of the investigator and the use of verbal encouragement, if a subject put forth maximal effort on a given trial was unknown.

A potential limitation of the current dissertation was the use of skin based measurements systems to detect changes in muscle activation and joint mechanics. For instance, electromyography signal can be influenced by: tissue characteristics, physiological cross talk between muscles, geometric change between the underlying muscle tissue and electrode, and external noise. The quality of electromyographic signal may depend on a proper skin preparation and electrode positioning. Thus, considerable effort was undertaken to properly prepare the skin to maintain low skin impedance and stable electrode contact throughout the testing procedures. At the electrode attachment site, the skin was lightly abraded and swabbed with an alcohol pad before securing with hypoallergenic elastic tape and powerflex tape or spandex shorts.

Also, the use of an external skin marker set to quantify joint kinematics may be a potential limitation of the current thesis. The theory of rigid body kinematics is based on the successful recording of marker trajectories, which are used to infer relative motion of an underlying rigid body, i.e. bone.[9] A major source of error and the primary limiting factor of skin-based systems is the excessive skin motion artifact[37-39], which may present the potential for erroneous data interpretation. This skin error may stem from marker wobble during dynamic landings and incorrect identification of anatomical landmarks.[55] Several steps were taken to minimize the impact of this potential problem. First, a single investigator (TNB) palpated anatomical landmarks and placed markers for all subjects.

Second, the kinematic data were processed with Visual 3D software, which utilizes a model-based least squares global optimization technique that is purported to make the results less sensitive to errors in maker trajectories.[124] We are confident, based on these precautions, that these errors have not confounded outcomes of the current study.

Although we are confident we accurately assessed changes in lower limb joint kinematics following the training, we did not, similarly, quantify the resultant changes in ACL strain. The current description of ACL loading and prediction of injury risk were based solely on lower limb joint biomechanics, which may be a potential limitation of the current dissertation. Currently, it may not be realistic to assess in vivo ACL strain during single-legged jump landings and therefore we based the prediction of ligament loading and subsequent injury risk on previous cadaveric data.[127, 128] It may be, however, the explicit quantification of how ACL injury prevention protocols modify resultant ACL strain is warranted and necessitates further research.

CHAPTER 7

Conclusion

CHAPTER 2

Purpose:

The purpose of this study was to examine the relation between explicit preparatory lower limb muscular activation patterns and knee joint biomechanics during a single-leg land and cut maneuver.

Findings:

1) Greater preparatory activity of the rectus femoris was associated with increased peak anterior knee joint reaction force during single-legged jump landings.
2) Preparatory rectus femoris and vastus lateralis activation had a significant association with peak stance knee flexion moment. Specifically, greater rectus femoris activation predicted decreased knee flexion torque, while increased vastus lateralis activation accounted for greater knee flexion moment during the jump landings.
3) No preparatory EMG patterns were identified as significant predictors of peak knee flexion and abduction angle or abduction moment.

Conclusion:

Preparatory quadriceps activation patterns were associated with high-risk knee joint biomechanics during a single-leg land and cut maneuver. Specifically, increased rectus femoris and vastus lateralis activation may coincide with greater sagittal plane loading of the knee joint during jump landings. Rectus femoris activation, however, may also correspond with a reduction in sagittal plane knee torque and thus its impact during landing warrants further research. Despite this fact, the current outcomes highlight the need for reduced quadriceps activation during single-legged landings as a possible means to reduce ACL injury risk. To promote “safer” knee neuromechanical profiles, future injury prevention efforts should focus on a reducing the reliance on quadriceps activation to provide adequate knee stability during dynamic movements. Future research is also needed to find explicit neuromuscular control strategies to target for reduced knee abduction motion and loading, since it is a touted biomechanical risk factor.

CHAPTER 3

Purpose:

This study sought to compare key lower limb biomechanical adaptations between bilateral and unilateral jump landings arising via a standard neuromuscular training program.

Findings:

1) Following neuromuscular training, training participants exhibited greater peak knee flexion posture during the bilateral landings, but not for the unilateral landings as compared to the control group.
2) Training modifications were only evident for peak stance knee flexion posture.

3) Bilateral landings exhibited significantly greater initial contact and peak stance hip and knee flexion, and greater hip adduction, as well as, greater peak stance knee abduction posture compared the unilateral landings.

Conclusion:

Following a neuromuscular-based ACL injury prevention program, recreational athletes retained stance phase knee flexion magnitudes during bilateral landings. Similar training-induced retention, however, does not appear evident for unilateral movements. To reduce current ACL injury rates and their associated sex-bias, training programs may need to include strategies that successfully modify “high-risk” knee joint biomechanical profiles during unilateral movements. Lower limb joint biomechanical profiles appear significantly different between unilateral and bilateral movements and further work is needed to determine training strategies that produce successful adaptations in each instance. Training-induced biomechanical adaptations are also sensitive to the experience level of the study population. Specifically, further investigation is warranted to assess the potential need of future training strategies to tailor methodologies to participant skill and experience level to obtain beneficial modifications.

CHAPTER 4

Purpose:

The purpose of this study was to examine the extent to which core stability and balance, and plyometric training, used as a single modality, can modify “high-risk” landing biomechanics as compared to a standard neuromuscular and no training groups.

Findings:

1) A standard neuromuscular training program produced significantly greater peak stance knee flexion angle during both bilateral and unilateral landings following training.
2) An isolated training program consisting of only plyometric exercises increased knee flexion and decreased hip adduction angle, and decreased knee abduction moment during bilateral landings following a six-week training period.
3) The significant modifications, following a plyometric protocol, however, were only evident during bilateral landings and do not appear to be transferred to a uinlateral maneuver.
4) An isolated training protocol of core stability and balance exercises did not produce substantial lower limb biomechanical modifications following training, but the sample size may have been inadequate to reach proper statistical power and thus make definitive conclusions.

Conclusion:

Isolated training with plyometric exercises appears to have the potential to modify both sagittal and frontal plane lower limb landing biomechanics. These substantial adaptations, however, were limited to simplistic, bilateral landings and do not appear to be retained during a unilateral landing. The standard neuromuscular training model, which integrated two or more training components, improved peak stance knee flexion posture during both the bilateral and unilateral landings. Considering unilateral landings present the greatest risk of ACL injury, therefore, it may be that integrated training protocols are necessary. Although core stability and balance training did not currently modify lower limb biomechanics, it may be a necessary factor to promote a “safe” neuromechanical profile during unilateral landings and warrants further research. With that said, future research remains warranted to develop shorter integrated training protocols that maximize participant compliance and ensure promotion of safe lower limb landing biomechanics.

CHAPTER 5

Purpose:

The final study sought to examine the extent to which isolated core stability and balance, and plyometric training produce adaptations of the neuromuscular control patterns that coincide with concomitant changes in lower limb biomechanics as compared to standard neuromuscular and no training groups.

Findings:

1) For the standard neuromuscular group, greater lateral hamstrings activation at the conclusion of training was associated with larger concomitant hip flexion moment and anterior knee joint reaction force.
2) During the single-leg landings, the core stability and balance group exhibited a significant relationship between training-induced changes of vastus lateralis and lateral hamstring co-contraction ratio with peak stance knee abduction posture. Specifically, greater hamstrings activity corresponded with a reduction in peak knee abduction angle.
3) For the plyometric training group, greater rectus femoris activation predicted larger hip flexion moment.
4) The no training group demonstrated larger vastus lateralis activity predicted a reduction in peak knee abduction angle.

Conclusion:

Neuromuscular-based training appears to produce adaptations of quadriceps and hamstring activation patterns are associated with changes of lower limb sagittal plane loading and frontal plane knee kinematics. To promote lower limb sagittal plane modifications, which coincide with a “safer” knee neuromechanical profile, future injury prevention programs may need to include plyometric exercises. Core stability and balance training, however, may warrant inclusion in neuromuscular-based training programs as a means to produce adaptations of lower limb muscular activation patterns that predict concomitant reductions in hazardous frontal plane knee motions. If these explicit sagittal and frontal plane biomechanical factors do, indeed, dictate injury risk, then future neuromuscular-based ACL injury prevention programs may only need to be composed of core stability and balance, and plyometric exercises to promote “safer” lower limb neuromechanical profiles.

CHAPTER 8

Recommendations for future work

The current collection of studies revealed the need for future work on ACL injury prevention programs. Future studies are needed to develop long-term beneficial neuromechanical adaptations that are retained during a realistic sports-environment. Currently, we do not know how long neuromechanical adaptations are retained after the conclusion of training, whether they are upheld during unanticipated maneuvers or if training combats the deleterious effects of fatigue. All of which, warrant further research.

Until the trained modifications that promote a “safer” neuromechanical are known, it will be difficult for an injury prevention protocol successfully target them. The current studies identified training induced adaptations of lower limb neuromuscular control strategies that predict a reduction in sagittal plane loading and frontal plane motions of the knee joint. Further study, however, is need to determine specific training modifications that coincide with a concomitant reduction of frontal plane loading and an improved sagittal plane posture of the knee joint during single-leg jump landings. Previous research suggests that quadriceps and hamstrings activation strategies may have the potential to modify knee abduction loads and thus may be a potential target for future injury prevention modalities to produce a reduction of these hazardous loading patterns. Modification of knee flexion posture, however, may not occur as a result of adaptations of quadriceps and hamstring activation patterns. It may be that joint excursions up and down the kinetic chain, i.e. greater hip and ankle flexion, promote changes in sagittal plane knee posture. Regardless, further study is needed to determine neuromuscular or biomechanical modifications that promote adaptations in lower limb neuromechanics during dynamic landings that have been identified as “true” predictors of injury risk. Currently, however, prediction of injury risk was based solely on the biomechanical patterns responsible for producing strain of the ACL in a cadaveric knee. It is imperative that research continues to understand in vivo ACL loading and strives to identify both the predictors of injury risk and injury mechanism during single-leg landings that may represent a non-contact injury scenario. Due to the difficultly of collecting in vivo strain data of the ACL, the development of an accurate biomechanical model of the knee joint may be an essential step to the continued assessment of the injury mechanism and predictors of risk. Assessing the effect of an ACL injury prevention program on ligament strain, possibly through modeling, may be an imperative step to improve the current prevention model.

Finally, the effect of the new, shorter injury prevention model recommended needs to be assessed. Assessment of this injury prevention model is required to determine whether it can promote neuromechanical adaptations during unilateral landings. Specifically, it needs to be addressed if it has the potential to promote greater knee flexion and a reduction of knee abduction motions and loads at the conclusion of training. If found to be successful, further study is warranted to determine if the shorter protocol can increase participant compliance and adherence rate while providing a reduction of non-contact

ACL injury rate that would be imperative to the long-term success of future injury prevention efforts.

CHAPTER 9

Literature review

This section aims to detail the Anterior Cruciate Ligament, specifically the 1) significance of anterior cruciate ligament (ACL) injury, 2) anatomy of the ACL, 2) non-contact ACL injury and mechanisms, 3) lower limb landing neuromechanics and 4) ACL injury prevention strategies.

ANTERIOR CRUCIATE LIGAMENT

The ACL is an essential structure of the knee joint. This key element of joint stability is formed by a complex organization of dense connective tissues.[60] Due to both the ligaments composition and orientation, it provides both mechanical and somatosensory functions. As a result, the ACL is one of the most frequently injured structures during high impact sporting activities.[196] The injured ACL often requires surgical reconstruction and may lead to early onset of degenerative changes within the joint.[123] Thus, the long-term impacts of ACL injury make it important to elucidate successful injury prevention strategies.

Anterior Cruciate Ligament Injury

Prevalence

Annually, up to 250,000 ACL injuries occur in the United States.[81] The vast majority of these injuries occur in individuals between 16 and 39 years old [79] while participating in sporting activities.[75] Although, in the general population males suffer more ACL injuries, females when participating in the same sports (e.g. basketball, soccer, volleyball) have greater injury rate.[2] For example, the incidence rate of ACL injury in female soccer and basketball players has estimated at 0.32 and 0.29 per 1000 hours of active playing, which is significantly greater than the rates evident, 0.12 and 0.11, for male soccer and basketball players, respectively.[11, 147] Ultimately, female athletes have been found to be anywhere between 2-8 times more likely to suffer an ACL injury when compared to males competing in similar activities.[2, 81]

Consequences

The direct and indirect consequences of ACL injury have been well documented. Most ACL injuries require surgical reconstruction[75] and physical rehabilitation with a direct cost that exceeds one billion dollars per year in the United States.[78] Indirectly, the consequences of ACL injury include both short- and long-term disability. Subsequent to ACL injury, there is a short-term loss of sports participation, decreased time at work and reduced academic performance.[72, 194] Furthermore, the ACL injury may lead to long-term disability through the development of osteoarthritis, with first radiographic conformation occurring 5-14 years after the injury.[123] In fact, it has been estimated that 70 % of reconstructed knees will display arthritic changes seven years after surgery.[184] Recent epidemiologic evidence suggests the sex disparity in ACL injury rate emerges during the second decade of life, specifically years 14-19.[10, 79] In the coming decades, it is likely that a large number of relatively young females (late 20's and 30's) will have substantial knee joint debilitation as a result of the long-term complications (i.e. osteoarthritis) from ACL injury. Thus, it is imperative that researchers develop an implicit understanding of causal factors that increase risk of ACL injury and verify prevention strategies that successfully counter the underlying factors of the injury.

ANATOMY OF THE ANTERIOR CRUCIATE LIGAMENT

Insertions

The band-like ACL runs anteriorlly, medially and distally through a large portion of the intercondylar notch on its course from its femoral origin to tibial insertion.[15] Proximally, the ligament attaches on the posterior aspect of the medial surface on the lateral femoral condyle.[76] The wider, stronger tibial attachment inserts on a fossa located anterior and lateral to the medial intercondylar eminence.[15, 76] Some fibers of the tibial insertion slip underneath the intermeniscal ligament to blend with the anterior and/or posterior horns of the lateral meniscus, as well.[60] As a result, ACL rupture is often associated with damage to other structural tissues within the knee joint complex, specifically concomitant mensicus tears.[164]

Ultrastructure

Similar to other soft connective tissue structures, the ultrastructural hierarchy of the ACL consists of multiple levels of collagen organization.[15, 48, 108, 217] The ligament is comprised of collagen fibrils tightly packed into fiber bundles before segmentation into fascicles. Specifically, the collagen matrix mainly consists of Type I fibrils [3], oriented parallel to the longitudinal axis of the ligament to provide great tensile strength, [60] and interspersed with Type III, [4, 229] Type IV [165] and Type VI [165] fibrils. It also has been reported there are Type II fibrils, a collagen type not usually found in ligaments, situated near the femoral and tibial attachments to provide the ligament resistance to pressure and/or shear forces.[60, 180] The remaining ligament matrix is composed of water, ground substance and elastic fibers[60], which permits stretch of the ligament during motion.

The fascicles are oriented in a complex, multi-hierarchal fashion. Centrally located fascicles are arranged in linear “waves” with the surrounding peripheral fascicles in a nonlinear, helical pattern that creates an accordion-like crimp.[60, 217] The undulating pattern of collagen fibrils of the ACL has specific biomechanical implications.[60, 217] The specific fibril organization provides a buffer for the ACL from excessive longitudinal elongation. During stretch of the ACL, small loads first straighten the fibril crimp before larger loads elongate the fibrils. As the ligament becomes increasingly loaded, a greater number of fibrils provide tension resulting in a gradual increase in stiffness. The result is a non-linear load-elongation curve of the ACL[129], which allows the ligament a mechanism to control tension and provide additional protection from damage. The unique structure of the ACL combines to form a ligament that can withstand multi-axial stresses and varying tensile strains.[60, 223]

Recent experimental evidence suggests that sex-based differences in ACL geometry and ultrastructure may contribute discrepancies in the maximal amount of stress and strain the ligament can withstand.[42, 89] The female ACL, which has been shown to be smaller in size[153] including reduced cross sectional area, length and volume compared to males[8, 42, 67, 153], may be mechanically weaker, as well. In support of this contention, is the fact that the female ACL may have a lower fibril concentration and percent area occupied by collagen fibrils compared to males.[89] Both stiffness and modulus of elasticity have been highly correlated with fibril concentration in female ACL, whereas, the male ACL has been correlated with percent area occupied by collagen fibrils.[89] It appears that the reduced fibril concentration and percent area of occupied by fibrils may lower the amount of strain, stress, strain energy and elasticity the female ACL can withstand compared to males.[41] Thus, the female ACL may have less resistance during straining and fail at lower stress levels compare to males.

Macrostructure

The ACL has been purported to be composed of two[76], three[7, 166] or many, 6-10, functional bundles.[151] Although, Amis and Dawkins[7] identified three bundles, anteromedial, posterolateral and intermediate, it has become widely accepted that the ACL is composed of two functional bundles.[15, 60, 76, 181] The double bundle organization groups the ACL into two functional bundles, anteromedial (AM) and posterolateral (PL).[76] The bundle names are based on their tibial attachment. The fascicles of the AM insert in the anterormedial portion and the PL fascicles occupy the posterolateral portion of the tibial insertion, respectively. Although, the ACL is actually a continuum of fascicles, researchers have reported the bundles exhibit functional differences. Throughout the entire joint range of motion, a portion of the ACL is taught with the reciprocal distribution of tension between the two bundles dependent on the amount of anterior drawer and degree of flexion of the knee.[102] During extension, the PL bundle lengthens and tightens while the AM becomes slack, and conversely the AM tightens during flexion while the PL becomes slack.[198]

Mechanical Function of the ACL

The primary role of the ACL is to provide sagittal plane stability of the knee joint. Specifically, the ACL is the primary restraint of anterior displacement of the tibia on the femur.[24, 36, 128] Combined with the posterior cruciate ligament, the ACL carries nearly all the anteriorly directed force at the knee joint.[185, 186] This ACL load is determined by the magnitude of anterior force [102, 128] and increases as knee flexion decreases.[13] Due to the fiber orientation of the ligament, each bundle (AM and PL) provides passive sagittal plane restraint differently.[198] The posterior fibers (PL) lengthen during extension and prevent hyperextension of the knee, while the anterior fibers (AM) tense and limit anterior translation during knee flexion.[36, 102]

The ACL may also have a secondary function to provide frontal and/or transverse plane stability of the knee joint. Although, researchers have suggested that the ACL limits excessive medial knee[186], internal rotation[127, 128, 185, 186], and coupled knee valgus and internal rotation[131] motions, the experimental evidence that the ligament is loaded from these respective torques is not conclusive.[132] It may be, the ACL only carries a small, insignificant portion [185] or is not loaded at all while the medial collateral ligament is intact when valgus torque is applied to the knee.[132] Woo et al.[241], however, concluded that the ACL is the dominant ligament resisting valgus motion and testing limitations may to be blame for current discrepancies. While the experimental evidence is inconclusive on whether the ACL is loaded during pure knee rotation or valgus torques, researchers do conclude knee valgus and internal rotation torques increase ACL load when the ligament is concomitantly loaded by anterior shear force.[24] Withrow et al. [236] purported that ACL increased 30 percent during compressive loading with combined valgus and flexion as compared to compressive loading in isolated flexion. It appears coupled valgus and/or internal rotation torques with anterior shear force produce ACL loading, which is greater in magnitude than that from anterior shear force alone.[24, 210]

Nerve Supply and Somatsensory Function of the ACL

Researchers reported that the ACL has an extensive intraligamentous neural network[202], which enters the ligament via an axon in the connective tissue and terminates in various mechanoceptors within the collagenous structure. The ligaments mechanoceptors include Ruffini end organs[202, 251], Pacinian corpuscles[202, 251] and free nerve endings[202, 251], which provide the central nervous system with information (i.e. position, motion and acceleration) to analyze joint kinesthesia[202], as well as, excitatory reflex feedback.[61, 113] The Ruffini end organs and Pacinian corpuscles provide the ligament tension and speed information, respectively, while the free nerve endings serve as a limited pain receptor system. Furthermore, the ACL’s nerve fibers provide afferent feedback to the central nervous system that elicits a muscular response of the surrounding knee musculature. Researchers have purported that either mechanical and electrical stimulation of the ACL can elicit a response in both the quadriceps[148] and hamstrings.[148, 189, 220] Specifically, it has been suggested that loading of the AM bundle evokes a hamstring activation while suppressing quadriceps activity, whereas, loading of the PL bundle elicits an excitatory response of the quadriceps.[189] While this ligamento-muscular reflex may increase co-activation of the hamstring muscles, which might counterbalance the forces on the quadriceps on the tibia and decrease ACL loading, it may not successfully prevent excessive ACL strain. Researchers have suggested that the reflex cannot be used as an automatic protection mechanism of the ACL because latency period is too long to activate muscle contraction to prevent ligament rupture.[61] The afferent feedback, however, may be essential to normal knee function by providing feed forward control used to coordinate complex motor activity[113] and improve functional knee stability.[18]

Blood Supply

Blood is supplied to the ACL through the middle genicular artery,[15, 201] which supplies a network of vessels that ensheath the entire length of the ligament. Although blood is provided to the ligament, the distribution is not homogenous or highly vascularized.[60] The combination of poor vascularization and high presence of fibrocartliage in of the ACL gives the ligament poor ability to heal itself. Thus, ACL injury often requires surgical reconstruction to repair a damaged ligament.

NON-CONTACT ANTERIOR CRUCIATE LIGAMENT INJURY

Non-contact ACL injuries account for 70 to 84 percent of all ACL injuries for both male and female athletes.[29, 66, 144] Of particular concern is the fact that females are 2-8 times more likely to suffer sports-related non-contact ACL injuries than males.[81] Typically the injury occurs during rapid deceleration followed by landing and/or pivoting[17] where the forces applied to the knee at the time of injury do not involve contact with another athlete or object.[75, 197]

ACL Injury Mechanism

The multi-factorial nature of the non-contact ACL injury mechanism has made it difficult to identify the etiology, as well as, implement successful injury prevention modalities. An ACL injury occurs when excessive tension force is applied to the ligament. Specifically, during the non-contact injury mechanism it appears a person, him or herself, generates the forces and/or moments at the knee that apply the excessive ACL loading.[244] Current cadaveric data suggest the primary determinant of ACL load is anterior shear of the proximal tibia[24, 127, 128], however, both anterior shear [56] and dynamic knee valgus [93] forces have been shown to be associated with ACL injury. Currently, it is debatable whether knee valgus and internal rotation moments can load the ACL with the collateral ligaments intact.[127, 132] It has been suggested, however, that coupled loading, anterior shear force in combination with dynamic knee valgus and/or internal rotation torques, produces the greatest amount of ACL strain.[24, 127, 210] Markolf et al. [127] concluded that coupled anterior and internal rotation force at full extension has the “greatest risk” of ACL injury, while synergistic anterior and valgus forces are “dangerous” with the knee in flexion of greater than 10 degrees.

Recent, videographic analysis suggests non-contact ACL injuries likely occur during a sudden deceleration to change direction or land on a single-leg, while the knee is at or near full extension with excessive quadriceps and reduced hamstring muscle activations.

[29, 111, 114, 167, 209] Koga et al.[111] analyzed the lower limb biomechanics from video evidence of 10 female ACL injuries and found that injured athletes landed with an extended knee (roughly 20 degrees), neutral abduction and externally rotated (5 degrees) posture and immediately went through valgus collapse[111], large knee abduction and internal rotation movements, during the landing phase leading to the position of no return.[104] Furthermore, a biomechanical model used to simulate non-contact ACL injury parameters found that injury occurred during trials with significantly reduced knee flexion posture at landing, and greater peak posterior ground reaction force, knee valgus and external rotation moments.[120]

Cadaveric [24, 127], videographic [29, 167]and biomechanical[120] evidence suggest that a majority of non-contact ACL injuries occur from lower limb neuromechanical patterns that coupled anterior shear force with dynamic knee valgus and/or rotational loading during single-leg cutting or landing maneuvers. Other mechanisms, however, may cause non-contact ACL injury as well, including excessive knee hyperextension[71] and hyperflexion [84], and also may warrant addressing during injury prevention methods.

Injury Risk Factors

The non-contact ACL injury mechanism appears to be governed by a combination of modifiable and non-modifiable risk factors.[81, 227] In this review, these factors will be divided in to environmental, anatomical, hormonal and neuromechanical categories, and discussed according to their potential for modification within injury prevention modalities.

Environmental

Environmental ACL injury risk factors include aspects external to the athlete. Researchers have previously studied the effects of meteorological conditions, playing surface, footwear and shoe-surface interaction on non-contact ACL injury risk. These extrinsic factors may pose greater ACL injury risk by increasing the coefficient of friction and torsional resistance of the shoe-surface interaction during play. Weather conditions purported to alter the shoe-surface interaction and increase injury risk are playing in warm temperatures[203] or on dry fields[169], whereas, surface such as grass type[170], artificial turf[168], and indoor fields[14], also, has been suggested to increase the coefficient of friction and pose greater injury risk. Furthermore, Ryder et al.[196] suggested that footwear design may be associated with injury risk by altering the torsional resistance between the shoe and playing surface to increase injury susceptability.[115] Although, environmental factors may pose an increased risk of non-contact ACL injury these factors may be largely uncontrollable and hence non-modifiable. Thus, environmental risk factors do not appear to be a candidate for successful manipulation within injury prevention modalities.

Anatomical

Anatomical factors may contribute to the overall stability of the knee joint and alter injury risk. Researchers have suggested that body mass index[81, 97], general[218] and specific knee joint laxity[227], as well as, q-angle[205] all are associated with increased injury risk. Although, these anatomical factors have been purported by researchers to increase injury risk, their association with injury risk is not conclusive[73, 74, 175] and may not make ideal candidates for manipulation within prevention strategies.

Other anatomical factors, such as knee morphology, may also have an association with injury risk. Knee joint geometry has been demonstrated to directly influence joint biomechanics.[5, 6, 149] Specifically, greater posterior slope of the lateral tibial plateau has been correlated with peak anterior joint reaction force[135] and may ultimately increase anterior shear loading of the knee joint during compression from dynamic landings. Greater anterior shear loading of the knee has been demonstrated to strain the ACL and may pose injury risk. Furthermore, previously ACL injured[33], particularly female[87, 88, 226], individuals possess larger posterior lateral tibial slopes compared to controls and males, respectively. This knee morphology may help explain the sexual dimorphism in injury rate, but would play a limited role in preventive strategies of non-contact ACL injury, as the ability to modify knee joint geometry is relatively small.

Another morphological characteristic of the knee joint that may predispose athletes to ACL injury is intracondylar notch width.[206, 227] A narrow notch has been proposed to impinge the ACL during dynamic activities, which may weaken or damage the ligament, however, the exact method of impingement is not fully understood.[58, 177] Furthermore, the intracondylar notch width has been correlated with ACL size.[58, 215] A narrow notch may indicate a narrow or small ACL, which has been proposed to be mechanically weaker than a larger ligament. Although, ACL volume has been suggested as a potential risk factor of injury this anatomical factors may not be ideal for modification within injury prevention modalities because the potential for modification is limited.

In conclusion, anatomical factors may be interesting but are not ideal for manipulation with injury prevention strategies. Further research on these factors, however, is warranted, as they may ultimately be successful tools for screening for increased injury risk prior to sports participation.

Hormonal

Hormonal risk factors may help explain the sexual dimorphism and contribute to the non-contact ACL injury rate. The human ACL, which contains both estrogen and progesterone receptors, may have its mechanical properties altered during fluctuations of hormones levels that occur with the menstrual cycle. Thus, during the three phases, follicular (day 0–9), ovulatory (day 10–14) and luteal (day 15–28), of the menstrual cycle injury risk may fluctuate. Considerable research has tried to identify the phase during which injury risk is the greatest, but disparity in the results exists. Researchers have identified the follicular phase [11, 12, 216], around ovulation [239, 240], or the luteal phase[161] as the phase when most ACL injuries occur. Although, previous researchers identified no conclusive phase, a recent meta-analysis concluded that the non-contact ACL injury risk is greatest during the first half of the cycle, as that is when most injuries occur.[101] It has been recently purported, however, that variations of the menstrual cycle did not affect hip and knee loading during jumping and landing tasks. Furthermore, both estrogen and progesterone purportedly affect collagen metabolism that could reduce the tensile properties of ligaments, but their effects on the failure strength and stiffness of the ACL are not well understood, nor conclusive. Thus, the observed differences in injury rates between menstrual phases might be more likely attributable to differences in strength, neuromuscular function, or ligament properties than movement mechanics.

Female sex hormones may blunt neuromuscular development and decrease musculoskeletal function. Sarwar et al.[200] reported that fluctuations of hormone levels during the menstrual cycle could alter musculoskeletal performance. Specifically, reduced muscular strength and relaxation rate, and increased fatigability[200], as well as, decreased motor coordination [187] have been shown as a result of varying hormone levels. Researchers, also, purported increased anterior knee joint laxity [211, 212] during the ovulatory or post-ovulatory phases; however, this association with injury risk is debatable.[16, 28] Although, fluctuations in hormone levels may alter the mechanical properties of the ACL current experimental findings do not conclude a specific phase of the menstrual cycle when injury risk is the greatest. With that in mind, the modification of hormone levels with injury prevention strategies is currently not warranted.

Neuromechanics

Neuromechanics quantifies the neuromuscular control strategies that govern movement and their relation to the subsequent biomechanical output that results during dynamic activities. Neuromuscular control provides dynamic stabilization of a specific joint from unconscious activation of the restraints surrounding a joint.[80] Specifically, sensory stimuli (proprioceptive, kinesthetic, vestibular and visual inputs) are processed to stabilize a specific joint. At the knee joint, activations of the quadriceps and hamstring are coordinated and co-activated, which results in movements in the sagittal, transverse, and frontal planes that provide crucial joint stability. These stabilizing movements are quantified as both joint kinematics and moments (i.e. biomechanical output) in all three planes. During movement, however, if ineffective overarching control strategies are used excessive stress can be place on the passive restraints of the joint (i.e. ACL), which may result in increased injury risk. With this in mind, considerable research has examined the relation of both joint biomechanics (kinematics and kinetics) and neuromuscular control (muscular activation strategies, muscle strength, stiffness and laxity) on ACL strain and ultimately injury risk.

Prospective data has identified lower limb neuromechanical profiles that are associated with increased ACL injury risk[248] and high-risk loading. The patterns linked with increased anterior shear loads include landing upright (extended hip and knee posture)[45, 125], increased posterior ground reaction force[204], and excessive quadriceps activation.[56, 204] Profiles that have been associated with increased dynamic valgus loading include greater hip adduction[94] and knee abduction motions[139], and increased external knee abduction moments[98], as well as, excessive lateral and reduced medial thigh muscle activation.[172] From prospective data researchers suggested increased lateral quadriceps and reduced medial hamstring pre-landing activation during single-leg landings are associated with greater ACL injury risk.[248] Hewett et al.[98], also, suggested that knee motion and loading are predictors of ACL injury risk in female athletes. Specifically, ACL injured athletes had 8 degrees greater knee abduction angle at landing and 2.5 times greater peak knee abduction moment than the uninjured athletes.

Neuromechanics of dynamic movement has been clearly identified as a risk factor of ACL injury. Unlike other injury risk factors, however, it has been suggested to be modifiable.[17] The ability to modify lower extremity neuromechanics makes it an ideal candidate for manipulation within injury prevention modalities.[17] With that in mind, injury prevention research has targeted lower limb biomechanics and neuromuscular control of dynamic movement.

LOWER LIMB LANDING NEUROMECHANICS

Neuromechanics of human movements not only appear to be an ideal candidate for manipulation with injury prevention strategies but, also, display a sex dimorphism and are adversely affected by factors synonymous with sports participation. Thus, successful modification of lower limb neuromechanics may substantially decrease the non-contact ACL injury, as well as, decrease the associate sex-disparity.

Sex Dimorphism

During dynamic sports landings, women's landing pattern has been repeatedly interpreted as "riskier". Women exhibit high-risk joint biomechanical patterns during landing including extended posture and increased out of plane motions and loads of the knee, which increase anterior shear and dynamic valgus loading of the knee joint. Specifically, women land with greater hip and knee extension[45, 53], as well as, greater hip adduction[94, 140] and knee abduction motions[69, 70, 109] dynamic jump landings. Women have also shown to use greater knee abduction loads[45, 139] compared to men during sports maneuvers. Importantly, women's lower extremity biomechanical pattern may increase their injury susceptibility because they have been prospectively linked to ACL injury and may increase ACL loading.

Women, also, use “high-risk” neuromuscular control strategies during dynamic landings. During dynamic sports tasks females exhibit neuromuscular imbalance, defined as muscle strength or activation patterns that increase joint loading.[95, 99, 155] Women have increased quadriceps dominance[85, 125, 162, 213], reduced hamstring activation[43, 125], and altered muscle activation amplitude and co-activation patterns compared to men,[64] all of which have been linked to increased knee joint loading.[43, 173] Furthermore, women have displayed significantly greater imbalance of the medial to lateral thigh muscle activation compared to males[172], which has been associated with greater valgus posture[173] and prospectively shown to increase ACL injury risk.[248]

The sex dimorphism of lower extremity neuromechanics may develop following puberty from the lack of neuromuscular spurt in adolescent women. Researchers have documented a substantial increase in muscular strength, coordination and performance in adolescent males, that is not present in the average adolescent female.[27, 106, 107] Not only does this neuromuscular spurt create performance discrepancies between genders, but it appears to significantly affect lower limb neuromechanics. Hewett et al.[96] found no significant gender differences of lower limb landing biomechanics in pre-pubertal athletes however, late and post-pubertal women use substantially greater knee abduction posture compared to males or pre-pubertal females, respectively. Furthermore, Yu et al.[246] found female adolescents decreased knee flexion but retained knee abduction posture with maturation, whereas, male adolescents reduced their knee abduction posture as they matured. It may be the lack of neuromuscular spurt or rather the insignificant increase in muscular strength and coordination in adolescent female athletes alters their lower limb neuromechanics. Furthermore, increased muscular strength and coordination may play an important role in injury prevention following puberty, as there is a significant divergence of injury rate between genders following puberty.[79] The fact that the sex dimorphism of non-contact ACL injury rate may stem from inadequate increases of strength and coordination of female athletes during puberty suggests the improved training during this period may provide an avenue for significant reduction in the sex disparity of ACL injury rate.

Unanticipated Movements

During sports participation, dynamic movements may be compromised by decision-making, which results in substantial, potentially hazardous lower limb neuromechanical modifications that may increase injury risk.[25, 31, 116] In gameplay where non-contact ACL injuries commonly occur, the athlete is required to successfully perform a complex series of random events up to 70% of the time.[222] These unanticipated perturbations produce "high-risk" modifications of lower limb biomechanical patterns including larger frontal and transverse plane hip and knee motions and loads. Specifically, decreased hip flexion[31, 34, 142] and increased hip and knee internal rotation[31, 142], and knee abduction[31, 51, 137, 142] posture are evident during anticipated movements, while increased hip and knee internal rotation[34, 142], and knee abduction[25, 142] loads are also displayed. Furthermore, the magnitude of the hazardous loading patterns during unanticipated movements has been suggested to be up two times greater than similar anticipated maneuvers, which may significantly increase the injury risk of these maneuvers.[25]

The potentially hazardous biomechanical loading patterns may stem from ineffective neuromuscular control strategies during random, complex movements. Besier et al.[26] found that during unanticipated cutting, the quadriceps and hamstrings musculature switched from a selective to general activation pattern and increased the amplitude of activation up to 25 percent compared to anticipated maneuvers. These anticipated movements, which lack the temporal constraint of unanticipated maneuvers may allow for a more preprogrammed movement strategy.[1] The preprogrammed muscle action would provide the central (spinal and supraspinal) control mechanisms with adequate time to stabilize joints[23, 52] and prevent the suboptimal muscle behavior that would occur from compromised processes evident during the unanticipated movements.[52] Ultimately, the reduced neuromuscular function as a result of sports synonymous factors (i.e. unanticipated movements) would adversely affect dynamic joint stabilization and present a worst-case scenario in terms of ACL injury risk[31, 136], contributing to high-risk lower limb landing neuromechanics.

Unilateral vs Bilateral Limb Movements

During sports landings, experimental evidence suggests significant and potentially important differences exist in lower extremity landing biomechanics between uni- and bi-lateral limb landings. Unilateral landings, for example, present substantially different sagittal and frontal plane hip and knee biomechanical patterns compared to bilateral landings. Specifically, decreased knee flexion[63, 163, 176], abduction[63, 163] and internal rotation[163], and increased hip adduction[63] rotations are evident during unilateral landings. Bilateral landings, however, display greater knee abduction postures compared unilateral landings. Both landings present “high-risk” biomechanical patterns, which can produce ACL strain. The extended posture during unilateral landings may increase the anterior shear at the knee joint, while the increased knee abduction during bilateral landings may produce dynamic valgus loading. Thus, both landings induce risky ACL load states and warrant inclusion within injury prevention modalities.

ACL INJURY PREVENTION STRATEGIES

Injury prevention modalities aim to improve dynamic knee joint loading by reducing both anterior shear and dynamic valgus forces during sports-related movements. The specific biomechanical adaptations injury prevention strategies aim to produce are increased knee and hip flexion, and reduced dynamic valgus motions (hip adduction, and knee abduction and rotation) and loads (external knee abduction and rotation). The specific neuromuscular control adaptations are improved hamstring and reduced quadriceps muscle activation, as well as, greater hamstring to quadriceps activation ratio, and improved medial to lateral thigh musculature activation.

To improve knee joint loading recent research has targeted neuromechanics of dynamic movement. The basis for this goal is the rationale that “lower-risk” landing neuromechanics[95, 99] can be achieved through successful modification of explicit lower extremity biomechanics[44, 90, 158] and neuromuscular control strategies.[231, 249] Neuromechanics is the focus of injury prevention programs because it is directly modifiable with training modalities [17] and exhibits a substantial sexual dimorphism.[195] Furthermore, prospective data has associated both ineffective neuromuscular control strategies and lower limb biomechanics with greater ACL injury risk.[98, 248] In light of the above findings, injury prevention strategies have been developed targeting modification of these high-risk neuromechanics.

Current Injury Prevention Programs

Current neuromuscular-based injury prevention protocols are based on the following components: core strength and balance, plyometrics, resistance, and speed training. Early neuromuscular training programs based on these components have purported successes [95, 99] and appear to combat high-risk lower limb neuromechanical outcomes during dynamic landing maneuvers.[155, 158, 178] Specific adaptations of lower limb biomechanics reported are decreased dynamic knee valgus motions and loads, and increased knee flexion posture.[44, 157, 158] Training modalities, also, have been shown to improve neuromuscular control strategies with increased gluteus medius [117] and hamstring activation, [231, 249] reduced quadriceps activation, [231] and improved hamstring to quadriceps co-contraction ratio.[119] The neuromechanical adaptations, however, are not consistent across all training programs[91], nor has the sex disparity in non-contact ACL injury rate decreased despite ever-increasing implantation of injury prevention programs.[2] Although, injury prevention programs have been shown to successfully modify both lower limb landing biomechanics and neuromuscular control strategies, their role in preventing non-contact ACL injury is not certain. Training-induced neuromechanical adaptations may differ between each component of current prevention strategies [157] and to date the specific modification from each training modality is unknown. Understanding how specific injury prevention modalities work in isolation would facilitate the development of effective and adaptable ACL injury prevention programs.

Prospective data reports both plyometric and proprioceptive (balance) based injury prevention programs reduce the incidence rate of non-contact ACL injury. Caraffa et al. [40] used balance board training to show a reduction of ACL injury rate in proprioceptive trained male athletes. Plyometric based programs, also, have been shown to reduce the incidence rate of non-contact ACL injury after training in female athletes.[95, 126] The reduction in injury rate for either balance or plyometric-based training, however, has not been consistent across all studies.[179, 182, 219] Soderman et al. [219] did not see a significant reduction in the injury rate of female athletes after proprioceptive training, while prospective analysis of plyometric training in high school-aged female soccer players did not show the reduction in ACL injury rate evident from other prevention programs.[182] Further analysis of the intervention protocols suggest a link between the specific training modalities used and successful reduction of injury rate. Pfeiffer et al. [182] employed a plyometrics based training regimen that did not include the dedicated resistance exercises included in the original, successful protocols.[95, 99] Recent meta-analysis of injury prevention programs further supports this analysis and concluded plyometic and resistance components are essential exercises for a successful protocol.[243] Thus, these results suggest a need to understand the contributions of each specific training modality of current injury prevention strategies to the resultant training-induced neuromechanical adaptations.

Training Components

Experimental findings report that the core strength and balance, and plyomteric components when combined with resistance training and used separately, can induce significant modifications of the lower limb biomechanical profile.[157] Myer et al. [157] found that plyometric, and core strength and balance training, produced significant modifications in the lower limb landing biomechanics, but their effects were dependent on the type of dynamic movement performed. After plyometric training, female athletes increased knee flexion angles during a drop vertical jump, whereas after balance training the athletes increased knee flexion angle during a single-legged medial drop-landing task. Furthermore, Cochrane et al.[49] suggested balance training used in isolation can lower high-risk landing biomechanics in competitive male athletes during single-leg cutting maneuvers. These results indicate both training protocols when used in concert with resistance exercises can produce significant modifications of the lower limb biomechanics and warrant inclusion into current injury prevention modalities. The experimental evidence, also, indicate training with a single modality may produce substantial modifications of the lower limb biomechanical profile following training, however, to date the effects of training with a single modality in female athletes is unknown.

Current experimental findings on the contribution of resistance training to injury prevention programs has had varied results.[49, 90, 91] Resistance training when paired with a video-assisted feedback program can produce neuromechanical alterations.[91] As a single modality, however, resistance training appears to be insufficient to produce beneficial modifications of lower limb neuromechanics.[49, 91, 133] Herman et al.[91] found training consisting of only resistance exercises did not produce any significant differences in hip and knee biomechanics during dynamic movement. These findings, however, were recently contradicted. Cochrane et al.[49] suggested that resistance training with machine weights had potential to lower ACL loading, but resistance training with free weight exercises elicited mixed results with respect to ACL injury. Further analysis of Cochrane et al.'s[49] methods, however, suggest serious limitations that prevent interpretation of their findings with confidence. Ultimately, a vast majority of experimental evidence suggests that resistance training in isolation cannot develop movement patterns that decrease ACL loading and reduce injury rate. A resistance modality of neuromuscular training, however, may be important and necessary training component because it has been suggested to produce adaptations of bone, ligament, and muscle that may be beneficial for injury reduction[68, 112], especially in female athletes.[96] Female athletes may lack the substantial increase in muscular strength, coordination and performance evident in adolescent males[27, 106, 107] during puberty making the benefits of resistance training important for injury prevention strategies in this population. The contribution of plyometric or balance training in isolation without the benefits of resistance training to prevention of non-contact ACL injury in females, however, is unknown and warrants further investigation. Further analyses are needed to determine if training-induced neuromechanical adaptations can result without resistance training in female athletes. The speed training component may be important to improve running mechanics, short distance speed, explosiveness, and increased muscular resistance to fatigue.[158] Speed training has reportedly been shown to improve athletic performance with increases in short burst acceleration and sprint speed by altering stride length and frequency, and increasing joint angular velocities.[154, 224, 247] Although, speed training has been incorporated into recent comprehensive injury prevention methods, to date it is unknown whether speed training methods can produce neuromechanical adaptations that improve knee joint loading. Furthermore, speed training techniques may be essential to improve athletic performance, but to date there is no experimental evident to suggest that speed training exercises aid the modification of high-risk ACL loading. Thus, speed training may not warrant inclusion within injury prevention methods.

Current Training Limitations

Despite the increasing number and complexity of prevention programs, current epidemiological data suggest ACL injury rates and the associated sex-disparity have not diminished.[2] It appears therefore, that current ACL injury prevention strategies may fail to successfully prevent key factors within the non-contact ACL injury mechanism. Both decision-making and unilateral landings have been shown to adversely affect lower limb neuromechanics and may contribute to increased injury risk. Current injury prevention methodologies, however, may fail to adequately counter the deleterious effects of both.

In the inherently random and demanding sports environment it is necessary for the athlete to successfully anticipate, react to and execute dynamic movements. These dynamic movements may be compromised by decision-making. During sports where non-contact ACL injuries commonly occur, the athlete is required to successfully perform a complex series of random events up to 70% of the time.[222] These random, unanticipated perturbations, realistic of sports participation, produce substantial, potentially hazardous lower limb biomechanical modifications that may increase ACL injury risk.[25, 31, 116] This reduced neuromuscular function as a result of sports synonymous factors may combine to present a worst-case scenario in terms of ACL injury risk, [31, 136] contributing to high-risk lower limb landing neuromechanics. Until recently, however, neuromuscular training programs promoted neuromechanical modifications based on controlled, systematic lab-based interventions.[160, 178] Thus, these injury prevention modalities, which fail to integrate random perturbations, do not account for the complex coordination of the central and peripheral processes evident during sports participation.[30] To facilitate the development of more successful injury prevention strategies, neuromuscular training protocols need to adequately counter these realistic sports factors.

Current neuromuscular-based ACL injury prevention programs are typically based on the rationale that “lower-risk” landing mechanics[95, 99] during sporting activities can be achieved through successful modification of explicit hip and knee postures[90, 158] and loads[44] elicited during bilateral (stop jump or drop vertical jump) landings.[44, 90, 158] In spite of these continued efforts and reported early successes[95, 99], however, ACL injury rates have endured.[2] One key reason for this shortcoming may be that training program “success” has been defined via a limited focus on the bilateral landing task, which may not truly reflect the sports-relevant landing maneuvers during which ACL injury commonly occurs.[81] Currently, little is known regarding whether trained neuromechanical adaptations are possible for unilateral landings[157], despite the fact most

ACL injuries occur during such tasks.[29, 100 167] Furthermore, experimental evidence suggests significant and potentially important differences exist in lower extremity landing biomechanics between uni- and bi-lateral landings. Unilateral landings, for example, present with noticeably different sagittal and frontal hip and knee biomechanical profiles compared to bilateral landings.[63, 163, 176] Basing the success of ACL injury prevention methods on the ability to modify lower limb biomechanics during isolated bilateral landings may thus be problematic. Determining if trained biomechanical adaptations during bilateral landings are similarly evident for unilateral landings, which more closely represent a non-contact ACL injury movement scenario, may be an important step in more effectively reducing injury rates. Currently, there is a paucity of training research examining the modifications of injury prevention protocols during unilateral landings.

To facilitate the development of successful injury prevention strategies, neuromuscular training protocols need to adequately counter unanticipated movements, as well as, produce modifications that are transferred to unilateral landings. Thus, evaluating the initial and long-term neuromechanical adaptations of the specific training modalities of current injury prevention strategies, shown to successfully reduce high-risk ACL loading in female athletes, to factors synonymous with realistic sports participation including unanticipated and unilateral landing maneuvers would aid in the development of effective and adaptable intervention strategies.

APPENDICES

APPENDIX A

Training components and exercise progressions.

Core stability and Balance Training:

The goal of this component was to attain core strength and stability levels that allow the subject to maintain balance and posture, while attenuating and subsequently regenerating force in the desired movement direction for successful execution of landing tasks. To achieve these goals, this component focused on maneuvers that targeted increased coordination, strength and stability of the core stabilizing muscles. The training sessions progressed from low to high-risk maneuvers by varying exercise intensity through increasing repetition, changing surface stability (BOSU Balance Trainer, Canton, OH. and Gymnic Stability Balls, San Diego, CA) and altering body position (e.g. arm position and open/closed eyes). The initial core strength and balance training sessions (Phase 1) were used to establish baseline core (hip and torso) strength and coordination of the participant. Next, exercises were introduced (Phase 2) to eliminate side-to-side balance, postural stability, and strength deficits. Finally, the last training sessions (Phase 3) focused on developing core neuromuscular control strategies that allowed proper repositioning and correction of body sway due to perturbations.

Table A.1. Core strength and balance exercises and progression during the six-week neuromuscular-based ACL injury prevention program.

Phase 1	Sets	Reps	Phase 2	Sets	Reps	Phase 3	Sets	Reps
SWISS Crunches	1	30	SWISS Crunches	2	20	SWISS Crunches	2	20
SWISS Lat. Crunch	1	20	SWISS Lat. Crunch	2	15	SWISS Lat. Crunch	2	15
SWISS Ball Lift	1	10	SWISS Ball Lift	2	10	SWISS Crunch – Feet on Ball	2	20
SWISS Side Ball Lift	1	10	SWISS Scissors – Ball Rot.	2	20	SWISS Ball Lift	2	10
SWISS Scissors – Ball Rot.	1	20	SWISS Superman	2	20	SWISS Side Ball Lift	2	10
SWISS Seated – Ball Catch	1	8	Russian Twist – Ball	2	20	SWISS Scissors	2	20
SWISS Superman	1	20	BOSU Bal. Knees – Ball Catch	1	6	SWISS Superman	2	20
Broad Jump – Stick, Hold	1	4	BOSU Bal Single – Eyes Closed	2	15 s	Russian Twist - Ball	2	20
BOSU Step Up – Squat	1	10	BOSU Lat. Hop	2	10	BOSU (f) Bal. Knees – Ball Catch	2	6
BOSU Lat. Step Up – Squat	1	10	BOSU Squat	2	5	BOSU (f) Bal. Single – Eyes Closed	2	15 s
BOSU Bal.	1	15 s	BOSU 180 Jump – Stick, Hold	2	6	BOSU Lat. Hop	2	15 s
BOSU Bal. – Single	1	15 s	Single Leg Hop	2	6	BOSU (f) Squat	2	10
BOSU Squat	1	5				BOSU 180 Jump – Stick, Hold	2	5
						Single Leg Hop	2	6
						Broad Jump – Stick, Hold	2	6

Plyometric Training:

The goal of this component was to develop proper landing technique (e.g. soft athletic landings with deep knee and hip flexion) and improve dynamic control of the center of mass. To achieve these goals, soft athletic landings were emphasized during double and single-leg jump landings tasks to develop sound athletic position and adequate control of center of mass. The training sessions began with a low volume of two-legged movement exercises, to safely introduce the training modality, before progressing to single leg movements and some instances multi-planar reactive landings. The initial training sessions (Phase 1) double-legged movements were used to emphasize balanced athletic position and to initiate the development of athletic power. After establishing athletic position, the sessions (Phase 2) continued the development of athletic power to stimulate explosive performance of double-legged movements in multiple planes of movement, as well as, introduced proper force attenuation strategies during single-limb tasks. Finally, the last training sessions (Phase 3) focused on developing neuromuscular control strategies that allow for safe cutting and landing technique in sports-related movements (e.g. reactive single-leg).

Table A.2. Plyometric exercises and progression during the six-week neuromuscular-based ACL injury prevention program.

Phase 1	Sets	Reps	Phase 2	Sets	Reps	Phase 3	Sets	Reps
Wall Jumps	1	15 s	Wall Jumps	1	15 s	Wall Jumps	1	15 s
Squat Jumps	1	15 s	Squat Jumps	1	15 s	Tuck Jumps	1	15 s
180 Jumps	1	30 s	Tuck Jumps	1	15 s	180 Jumps – Speed	1	15 s
Bounding	1	15 s	180 Jumps	1	15 s	Triple Broad – Vert	2	5
Front/Back Jumps	1	15 s	Front/Back Jumps	1	15 s	Hop, hop, hop – Stick	2	6
Side/Side Jumps	1	15 s	Side/Side Jumps	1	15 s	Crossover hop, hop, hop – Stick	2	6
Broad Jumps	1	5	Broad Jumps – Stick	1	5	X-Hops	2	6
Triple Broad – Vert	1	5	Triple Broad – Vert	1	5	Scissor Jumps	2	6
Scissor Jumps	1	6	Hop, hop, hop and stick	2	6	Box Jumps	2	6
Hop, hop, hop, stick	1	6	Crossover hop, hop, hop and stick	2	6	Box Drops	2	6
Box Jumps	1	6	180 Jumps – Ball Catch	1	6	Depth Jumps	2	6
			Scissor Jumps	1	6	Box-Depth-180-Box-Depth-Vertical	1	6
			Box Jumps	2	6			
			Box Drops	2	6			

Resistance Training:

The goal of this component was to increase muscular strength and power of the major muscle groups by performing exercises with resistance bands and medicine balls (Perform Better Inc., Cranston, R.I.). To achieve these goals, participants tried to achieve a pre-defined number of repetitions as they progressed from multi-joint to alternating upper and lower-body exercises during each session. The amount of weight was increased if the pre-defined number of repetitions was successfully achieved, in conjunction with proper and safe technique. If correct technique is not used, weight was reduced until proper technique was restored. The initial training sessions (Phase 1) were used to introduce proper exercise form and began the development of total body strength. After introducing proper technique, the training sessions (Phase 2) continued strength development and began the introduction of explosive exercises to increase power. Finally, the last training sessions (Phase 3) tried to maximize strength and power growth.

Table A.3. Resistance exercises and progression during the six-week neuromuscular-based ACL injury prevention program.

Phase 1	Sets	Reps	Phase 2	Sets	Reps	Phase 3	Sets	Reps
SWISS Back Wall Squat	2	8	Squat and Throw – Ball	2	8	Squat and Throw – Ball	2	12
SWISS Push-up	2	8	SWISS Push-up	2	8	SWISS Push-up	2	12
Lunge – Ball Twist	2	12	SWISS Back Wall Squat	2	8	SWISS Back Wall Squat	2	8
Band Stand Pull	2	8	Push-up - Ball	2	8	Push-up - Ball	2	8
Calf Raise	1	15	Lunge – Ball Twist	2	12	Lunge – Ball Twist	2	12
Band Stand Press	1	8	Band Stand Pull	2	8	Band Stand Pull	2	12
Figure 8 - Ball	1	15 s	Calf Raise	1	15	Calf Raise	2	15
			Band Stand Press	2	8	Band Stand Press	2	12
			Figure 8	2	15 s	Figure 8	2	15 s

Speed Training:

The primary goal of this component was to improve muscular endurance, explosiveness, and running mechanics (e.g. proper arm swing, stride length, foot strike, forward leg swing, and trunk posture). To achieve these goals, timed short interval sprints of varying light, medium and heavy resistance were performed while a trainer provided visual and verbal feedback on proper running biomechanics. Standard “therabands” (Jump Stretch Inc., Youngstown, OH) were tied together and anchored around the waists of partnered subjects to provide the running resistance. To standardize the resistance between subjects a goal distance was set for them to reach in the prescribed time frame. Each session concluded with a maximal, non-rested sprint of varying distance. The training sessions began with low volume and light intensity before progressively increasing repetition and resistance. The initial speed training sessions (Phase 1) were used to develop proper running mechanics and form before increasing resistance (Phase 2) to develop greater explosiveness. Finally, the last training sessions (Phase 3) increased the volume of resisted sprints to improve muscular endurance.

Table A.4. Speed exercises and progression during the six-week neuromuscular-based ACL injury prevention program.

Phase 1	Sets	Reps	Phase 2	Sets	Reps	Phase 3	Sets	Reps
Jog to Sprint	1	10 s	Jog to Sprint	1	10 s	Jog to Sprint	1	10 s
March – Light	1	6 s	March – Light	1	6 s	March – Light	1	6 s
Skipping – Med.	1	6 s	Skipping – Med.	2	10 s	Skipping – Med.	2	10 s
Run	1	10 s	Backwards Run	2	6 s	Backwards Run	2	6 s
Run – Light	2	6 s	Run – 90%	1	10 s	Run – 90%	1	10 s
Run – Med.	2	6 s	Run – Light	1	6 s	Run – Light	1	6 s
Run – 100%	1	10 s	Run –Med.	3	6 s	Run –Med.	2	6 s
			Run – Heavy	1	6 s	Run – Heavy	3	6 s
			Run – 100%	1	10 s	Run – 100%	1	10 s

APPENDIX B

Consent forms

Informed consent

UNIVERSITY OF MICHIGAN
CONSENT TO BE PART OF A RESEARCH STUDY

INFORMATION ABOUT THIS FORM

Your child may be eligible to take part in a research study. This form gives you important information about the study. It describes the purpose of the study, and the risks and possible benefits of participating in the study.

Please take time to review this information carefully. After you have finished, you should talk to the researchers about the study and ask them any questions you have. You may also wish to talk to others (for example, your friends, family, or other doctors) about your child's participation in this study. If you and your child decide for them to take part in the study, you will both be asked to sign this form. *Before signing this form, be sure you understand what the study is about, including the risks and possible benefits to your child*.

1. GENERAL INFORMATION ABOUT THIS STUDY AND THE RESEARCHERS

1.1 Study title: Integrated structural, strength and mechanical contributions to ACL injury and knee osteoarthritis risk in the maturing knee joint – **Phase 3**.

1.2 Company or Agency sponsoring the study: University of Michigan Bone and Joint Injury Prevention and Rehabilitation Center

1.2 Names, degrees, and affiliations of the researchers conducting the study:
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Jessica Deneweth, MSc - School Kinesiology, University of Michigan
Tyler Brown, MSc – School of Kinesiology, University of Michigan
Ganapriya Venkatasubramanian, MSc – School of Kinesiology, The University of Michigan

2. PURPOSE OF THIS STUDY

2.1 Study Purpose:
Anterior cruciate ligament (ACL) injuries are common traumatic sports-related injuries that occur during landing or pivoting movements such as sidesteps. These injuries occur more often women, and require lengthy rehabilitation, with individuals rarely returning to pre-injured levels of competition. These injuries typically occur due to a combination of non-modifiable and modifiable factors, although we are still unsure as to how these factors come together during an actual injury. By non-modifiable, we mean factors that you cannot change, such as your anatomy. By modifiable, we mean things that you can train, such as your coordination or neuromuscular control. Currently, much of the research into ACL injuries focuses on understanding how movement coordination and control may contribute to injury risk, since such factors can be trained. Despite the increased number and quality of training programs aimed at reducing ACL injury risk, however, injury rates have remained. We propose, therefore, that current prevention methods fail to effectively address the underlying causes of ACL injury. In order to develop more effective training programs, the limitations of current methods must first be determined. Hence, the purpose of this phase of the investigation is to determine which components of typical ACL prevention training programs contribute to a reduction in ACL injury risk. Also, the ability of these programs to be successful during realistic sports participation and to be retained over a long period of time will also be examined. Outcomes of this study will provide immediate benefits to current ACL injury prevention methods. Ultimately, it is hoped that findings arising from this research will assist in the future reduction and possible prevention of anterior cruciate ligament injuries in everyone.

3. INFORMATION ABOUT STUDY PARTICIPANTS (SUBJECTS)

Taking part in this study is completely voluntary. Your child does not have to participate if they don't want to. They may also leave the study at any time. If they leave the study before it is finished, there will be no penalty to them, and they will not lose any benefits to which they are otherwise entitled.

3.1 Who can take part in this study?
We are looking to recruit healthy female subjects between the ages of 10-18, currently participating in volleyball, basketball, soccer, lacrosse or football activities. We have chosen these activities since they represent sports in which ACL injuries are common and also regularly include the movements that we intend to examine in the current investigation. As a result, we will necessarily recruit subjects experienced in performing such movements for this group. All study participants cannot have any previous history of a serious hip, knee or ankle injury or surgery; they cannot be currently be experiencing knee pain, suffer from a heart condition or be pregnant. Subjects in the sports landings group must also be willing to do approximately 30 minutes of jumping exercises in our laboratory. If your child meets all of these qualifications, they can be in the study.

3.2 How many people (subjects) are expected to take part in this study?

We will enroll 120 participants to take part in this phase of the study.

4. INFORMATION ABOUT STUDY PARTICIPATION

4.1 What will happen to me in this study?

After your child has been enrolled within the study, they will first be classified into one of six training groups. Subjects in all groups will be required to complete three separate testing sessions, during which, physical performance and lower limb joint movements and forces will be examined each time. Physical performance testing will include measures of lower limb strength and speed. Testing sessions will be conducted one week prior to, immediately following (within two days) and six weeks after a six week training program, which your child will be required to undertake, based on which group they are initially randomly allocated to. The details of the various activities involved in each training group are provided in more detail below.

Performance and Biomechanical Testing Sessions

Your child will be asked to take part in three testing sessions, with each lasting about 90 minutes. As noted above, the testing sessions will include the same test procedures on each occasion, and will take place one week prior, immediately following and 6 weeks after a six week training program. Specifically at each testing session, your child will have lower limb joint movements and forces and muscle activity and physical performance measures recorded. All testing for this session will be conducted within the Injury Biomechanics Laboratory of the Division of Kinesiology, The University of Michigan. A more detailed description of each of the measures recorded during this session is provided below.

Lower Limb Movements and Forces and Muscle Activity: At each testing session, you child will first be required to perform approximately 30 successful anticipated jump and land tasks. These tasks will include both double and single (left and right) leg landings and your child will be required to successfully perform approximately ten of each of these tasks. When they land, they will have to jump to the left, right or vertically as quickly as possible. They will be told which direction to jump by a series of lights (Figure 1). If L1 comes on, they will be required to land on the left foot only and jump quickly to the right. If L2 comes on, they will be required to land on the right foot only and jump quickly to the left. If L3 comes on, they will land on both feet and jump vertically as high as possible. For these trials, the light will come on well before they are asked to initiate a jump and land, so that they know exactly which way to move in advance.

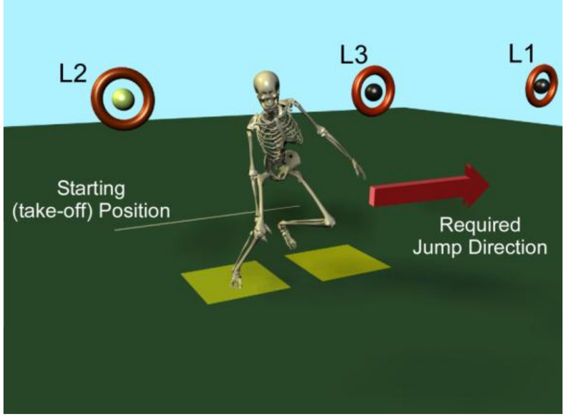

Figure 1: You will be asked to jump forward and after landing, move immediately in a specific direction, based on which of the 3 lights turn on.

Following completion of the anticipated jump and land tasks, your child will be given a ten minute rest period. Following this, they will be required to perform a second series of jump and land tasks, only this time the movements will be unanticipated and your child will be fatigued. To make these tasks unanticipated, we will use the same light and jump sequence as defined above. This time, however, the stimulus light directing which way to move following landing will not come on until they are already in mid air. To induce fatigue progressively, your child will be required to perform continuous sets of 8 double-leg squats between each jump trial. Your child will be required to alternate between squats and jumps until fatigue is reached, being defined as the point when you can no longer perform three squats in succession. Your child will be able to place the non-fatigued leg on a platform for stability during the single leg squats. As for the anticipated trials, the jump sequence and decision type will again be randomized. From our previous studies using these same methods to fatigue people, we expect that your child will be able to perform approximately 40 jump trials (320 squats) prior to maximum fatigue.

During all movement tasks, your child will have 28 reflective markers attached to their body, which, in conjunction with special high-speed video cameras, will allow us to measure their joint movements and forces. The markers will be attached directly to the skin using adhesive tape and will not cause any discomfort. As some markers are required to be attached to the thigh and pelvis, your child will be asked to wear bicycle shorts and sports bra during all testing procedures.

We will also be collecting muscle electromyographic (EMG) data during the movements so we can determine how active your child's muscles are. They will have 16 small EMG electrodes attached to the skin over various leg muscles, which will record their activity during each landing. In order to obtain a maximum signal from these electrodes, we will need to shave and lightly abrade (with plastic gauze) the skin where the electrode will be placed prior to cleaning it with alcohol. Your child may feel a brief stinging sensation when the alcohol is applied, but the electrodes will cause them no discomfort after this point.

Physical Performance Testing: At each testing session, your child will be required to take part in physical performance testing to determine how effective each training program was. Specifically, the strength of various leg muscles will be determined for your child. Two large pads will first be placed on the front of both of your child's thighs and secured with bandages. They will be positioned and strapped into a device that measures their muscle strength. They will be asked to sit in a chair attached to the device with their knees bent (Figure 2). Once they are comfortably positioned, they will be asked to kick out and pull back their leg as quickly and aggressively as possible while we measure how much strength they are producing. After a brief rest (approximately 5 minutes), they will then be asked to hold their leg stationary as best as possible while the device tries to move it.

Figure 2: Muscle Strength test

Your child will also be required to perform two specific types of single leg hops to determine their power and coordination. First, they will be required to stand on one leg and hop forward as far as possible and land on the same leg. They will do this three times and the greatest hop distance will be recorded. Your child will then be required to hop forward for six meters as fast as possible. They will also do this three times and the fastest time will be recorded.

Training Protocols

As noted above, your child will be randomly allocated to one of six training groups as part of this study. Training for each group will last six weeks, with three training sessions per week and each session. The goal of these training programs will be to improve your child's coordination and performance when they perform landing tasks typical of various sports. In doing so, we hope to reduce the risk of your child suffering an anterior cruciate ligament injury in the future. The six training groups are as follows:

Group 1: Core Stability and Balance
Group 2: Plyometrics
Group 3: Resistance
Group 4: Speed
Group 5: Standard Neuromuscular Training
Group 6: Control (no training).

If your child is allocated to the Core Stability and Balance, Plyometrics, Resistance or Speed training groups, their training sessions will last approximately 65 minutes, including a warm-up and warm-down. A brief description of each of these training programs is provided below.

Core Stability and Balance Training: The goal of the Core Strength and Balance Training will be to have your child attain core strength and stability levels that will enable improved balance, posture and power production. To achieve this goal, this training component will focus on a gradual increase from low to high-intensity movements that target increased coordination, strength, and stability of the core stabilizing muscles. Your child will also perform movements on different surfaces and with different body positions to increase these benefits. The exercises we have chosen for this training component have been derived from previously published core strength and balance training programs.

Plyometrics: The goal of the Plyometrics training component will be to improve your child's ability to develop safe and correct landing techniques and to improve their ability to control their body during rapid movements. We have again derived exercises from programs that have been able to reduce possible ACL injury risk in the past. Your child will be initially asked to perform relatively simple two-legged movement and landing exercises. As their techniques improve movements will become more difficult, progressing to single leg landings and movements in multiple directions. Your child will be given regular verbal feedback by the trainers throughout the training program to further improve their movement and landing techniques.

Resistance Training: The goal of the Resistance Training component is to increase your child's muscular strength and power. This training program will start with low intensity exercises and gradually progress to high intensity exercises. Training will focus on both upper and lower body strength and power development. Specifically, your child will be required to lift or work against weights for this training component, with the amount of weight being increased as the training program progresses. The trainers will prescribe all weights for resistance tasks that your child performs and will provide detailed demonstration and instruction on proper techniques before your child is asked to perform any training tasks. If we see that your child is unable to maintain a correct and safe technique during training, we will reduce the weight immediately and re-demonstrate the exercise.

Speed Training: The primary goal of the Speed Training component will be to improve your child's muscular endurance, how quickly and powerfully they can move, and running mechanics. Specifically, your child will be required to perform timed short interval sprints, while moving against light, medium or heavy resistance. The resistance is provided by having your child attached to an large elastic band which tries to pull them in the other direction as they run. These methods are used frequently by sprinting athletes to improve their strength and power. The trainers will provide your child with ongoing visual and verbal feedback on proper running technique throughout the training. At the end of each training session, your child will be required to perform a maximal, non-resisted sprint to assess their ongoing performance.

Standard Neuromuscular Training: If your child is allocated to the standard neuromuscular training group, each training session will last approximately 110 minutes, including warm-up and warm-down. In addition, each session will include three specific 30 minute components. The three components will be 1) Core stability and balance training, 2) Plyometrics and 3) Resistance and speed training. Each of these components will basically be the same as those described above, only shorter.

Control (no training): If your child is allocated to this group, they will not be required to partake in any training. They will still, however, be required to attend the three testing sessions at the appropriate times.

4.3 When will my participation in the study be over?

Your child will not be required to participate in any further testing sessions for this study. As a result, participation will be completed at the end of the third 90 minute testing session. They will thus be involved in the study for a period of approximately 13 weeks. Training sessions will be conducted three times per week for the six week training program. Each session will last approximately 60-90 minutes. Hence, your child will be required to train for up to 270 minutes per week if they take part in this study.

5. INFORMATION ABOUT RISKS AND BENEFITS

5.1 What risks will I face by taking part in the study? What will the researchers do to protect me against these risks?

<u>*The known or expected risks are:*</u> Since your child may be performing unanticipated jump and landing movements at relatively high speeds and in a fatigued state, there is the possibility that they may suffer some form of joint or muscle injury during the study. Also, as they will be undergoing maximal strength testing, muscle injury may again arise. They will also likely feel muscle soreness in the days following these strength tests. This is normal and should disappear after about 3 days. Considering the vigorous nature of some tests that your child may be involved in, there is the possibility of an abnormal

cardiovascular response. These responses could include abnormal heartbeats, abnormal blood pressure response, and in rare instances heart attack. Considering your child's age and current fitness level however, such responses are unlikely.

<u>The researchers will try to minimize these risks by:</u> To minimize the potential for the above risks, your child will be given ample time for a warm up and stretching, and to become familiar with each movement task prior to taking part in the study.

There is also the potential risk of loss of confidentiality through participation in this study. Every effort will be made to keep your child's information confidential, however, this cannot be guaranteed. Some of the questions we will ask your child as part of this study may make them feel uncomfortable. They may refuse to answer any of the questions and they may take a break at any time during the study. They may stop their participation in this study at any time.

As with any research study, there may be additional risks that are unknown or unexpected.

5.2 What happens if I get hurt, become sick, or have other problems as a result of this research?

The researchers have taken steps to minimize the risks of this study. Even so, your child may still have problems, or side effects, even when the researchers are careful to avoid them. Dr. Palmieri-Smith, a key researcher in this study, is a certified athletic trainer able to evaluate and manage musculoskeletal injuries. Thus, if an injury were to occur Dr. Palmieri-Smith would manage the condition and refer your child to a physician for further evaluation. Furthermore, Dr. McLean and Dr. Palmieri-Smith are certified as professional rescuers and are capable of performing CPR and using a defibrillator in case of a cardiac emergency. Please tell the researchers listed in section 10 about any injuries, side effects or other problems that your child has during this study. You should also tell their regular doctors.

5.3 If I take part in this study, can I also participate in other studies?

<u>Being in more than one research study at the same time, or even at different times, may increase the risks to your child. It may also affect the results of the studies</u>. Your child should not take part in more than one study without approval from the researchers involved in each study.

5.4 How could I benefit if I take part in this study? How could others benefit?

Your child may not receive any personal benefit from being in this study. Others, however, may ultimately benefit from the knowledge obtained in this study. Specifically, your child's participation may help us to gather knowledge that may be beneficial for the field of sports medicine as a whole, particularly in terms of reducing current anterior cruciate ligament injury rates.

5.5 Will the researchers tell me if they learn of new information that could change my willingness to stay in this study?

Yes, the researchers will tell you if they learn of important new information that may change your willingness to stay in this study. If new information is provided to you after you have joined the study, it is possible that you may be asked to sign a new consent form that includes the new information.

6. OTHER OPTIONS

6.1 If I decide not to take part in this study, what other options do I have?

Your child's participation in this project is voluntary. Even after they sign the informed consent document, they may decide to leave the study at any time without penalty or loss of benefits to which they may otherwise be entitled. As the researchers about other options you may have.

7. ENDING THE STUDY

7.1 If I want to stop participating in the study, what should I do?

You are free to leave the study at any time. If you leave the study before it is finished, there will be no penalty to you. You will not lose any benefits to which you may otherwise be entitled. If you choose to tell the researchers why you are leaving the study, your reasons for leaving may be kept as part of the study record. If you decide to leave the study before it is finished, please tell one of the persons listed in Section 10 "Contact Information" (below).

7.2 Could there be any harm to me if I decide to leave the study before it is finished?

Your child can leave the study at any time before it is finished without any harm.

7.3 Could the researchers take me out of the study even if I want to continue to participate?

Yes. There are many reasons why the researchers may need to end your child's participation in the study. Some examples are:

- ✓ The researcher believes that it is not in your child's best interest to stay in the study.
- ✓ Your child become's ineligible to participate.
- ✓ Your child's condition changes and they need treatment that is not allowed while they are taking part in the study.
- ✓ The study is suspended or canceled.

8. FINANCIAL INFORMATION

8.1 Who will pay for the costs of the study? Will I or my health plan be billed for any costs of the study?

There will be no costs to you or your child for participating in this study. By signing this form, you do not give up your right to seek payment if you are harmed as a result of being in this study.

8.2 Will I be paid or given anything for taking part in this study?

For each performance and biomechanical testing session in which your child participates they will receive $20.00. That is, they will receive a total of $60 for these combined (session 1, 2 and 3) testing sessions. Your child will also receive $15 for each week (3 sessions per week) of training they complete. They will therefore receive up to an additional $90 for taking part in the six week training program. If your child is allocated to the control group, they will only receive remuneration for the 3 performance and biomechanical testing sessions.

8.3 Who could profit or financially benefit from the study results?

No person or organization has a financial interest in the outcome of the study.

9. CONFIDENTIALITY OF SUBJECT RECORDS

The information below describes how your child's privacy and the confidentiality of your research records will be protected in this study.

9.1 How will the researchers protect my privacy?

Your child will not be identified in any reports on this study. Your research information will be stored in a locked cabinet. Research records will be kept in a separate research file that does not include names, registration numbers, or other information that is likely to allow someone other than the researchers to link the information to you. Records will be confidential to the extent provided by federal, state, and local law.

9.2 What information about me could be seen by the researchers or by other people? Why? Who might see it?

Signing this form gives the researchers your permission to obtain, use, and share information about your child for this study, and is required in order for you to take part in the study. Information about your child may be obtained from any hospital, doctor, researcher, and other health care provider involved in your care, including:

- All test results (MRI's, motion tests, etc.)
- All records relating to your child's prior surgeries which may enable them to participate in the study.

There are many reasons why information about your child may be used or seen by the researchers or others during or after this study. Examples include:

- The researchers may need the information to make sure your child can take part in the study.
- The researchers may need the information to check your child's test results or look for adverse effects.
- University, Food and Drug Administration (FDA), and/or other government officials may need the information to make sure that the study is done in a safe and proper manner.
- Study sponsors or funders, or safety monitors or committees, may need the information to:
    - Make sure the study is done safely and properly
    - Learn more about adverse effects
    - Analyze the results of the study
- The researchers may need to use the information to create a databank of information about your condition or its treatment.
- Information about your study participation may be included in your regular UMHS medical record.
- If your child receives any payments for taking part in this study, the University of Michigan accounting department may need your name, address, social

security number, payment amount, and related information for tax reporting purposes.

- Federal or State law may require the study team to give information to government agencies. For example, to prevent harm to your child or others, or for public health reasons.

The results of this study could be published in an article or presented at a scientific meeting, but would not include any information that would let others know who your child is. If your child's pictures will be used in any publications or presentations, the researchers will ask for your separate written permission.

9.3 What happens to information about me after the study is over or if I leave the study before it is finished?

As a rule, the researchers will not continue to use or disclose information about your child, but will keep it secure until it is destroyed. Sometimes, it may be necessary for information about your child to continue to be used or disclosed, even after they have left the study or the study is over. Examples of reasons for this include:

- To avoid losing study results that have already included your child's information
- To provide limited information for research, education, or other activities (This information would not include your child's name, social security number, or anything else that could let others know who they are.)
- To help University and government officials make sure that the study was conducted properly

10. CONTACT INFORMATION

10.1 Who can I contact about this study?

Please contact the researchers listed below to:

- Obtain more information about the study
- Ask a question about the study procedures or treatments
- Leave the study before it is finished
- Express a concern about the study

Study Coordinator: Ganapriya Venkatasubramanian, MS.
Mailing Address: School of Kinesiology, University of Michigan, 401 Washtenaw Avenue, Ann Arbor, MI, 48109-2214
Telephone: 734-647-1669
Email: vgpriya@umich.edu

Principal Investigator: Scott McLean, Ph.D.
Mailing Address: 3740 CCRB, School of Kinesiology, University of Michigan, 401 Washtenaw Avenue, Ann Arbor, MI, 48109-2214
Telephone: 734-764-5237
Email: mcleansc@umich.edu

You may also express a concern about a study by contacting the Institutional Review Board listed below, or by calling the University of Michigan Compliance Help Line at 1-888-296-2481.

University of Michigan Medical School Institutional Review Board (IRBMED)
Argus I
517 W. William
Ann Arbor, MI 48103-4943

Telephone: 734-763-4768
Fax: 734-615-1622
e-mail: irbmed@umich.edu

If you are concerned about a possible violation of your privacy, contact the University of Michigan Health System Privacy Officer at 1-888-296-2481.

When you call or write about a concern, please provide as much information as possible, including the name of the researcher, the IRBMED number (at the top of this form), and details about the problem. This will help University officials to look into your concern. When reporting a concern, you do not have to give your name unless you want to.

11. RECORD OF INFORMATION PROVIDED

11.1 What documents will be given to me?

Your signature in the next section means that you and your child have received copies of all of the following documents:

- This "Consent to be Part of a Research Study" document.

(*Note: In addition to the copy you receive, copies of this document will be stored in a separate confidential research file and may be entered into your regular University of Michigan medical record.)*

15. SIGNATURES

Research Subject:

I understand the information printed on this form. I have discussed this study, its risks and potential benefits, and my other choices with ____________________. My questions so far have been answered. I understand that if I have more questions or concerns about the study or my participation as a research subject, I may contact one of the people listed in Section 10 (above). I understand that I will receive a copy of this form at the time I sign it and later upon request. I understand that if my ability to consent for myself changes, either I or my legal representative may be asked to re-consent prior to my continued participation in this study.

Signature of Subject: ____________________Date: ______________________

Name (Print legal name): _________________

Legal Representative/s (if applicable):
Signature of First Person Legally
Authorized to Give Consent_________________ Date: ____________________

Name (Print legal name): _________________Phone: ______________________

Address: ______________________________
Check Relationship to Subject:
☐Parent ☐Spouse ☐Child ☐Sibling ☐Legal Guardian ☐Other:

Signature of Second Person Legally
Authorized to Give Consent_________________ Date: ____________________

Name (Print legal name): _________________ Phone: ______________________

Address: ______________________________
Check Relationship to Subject:
☐Parent ☐Spouse ☐Child ☐Sibling ☐Legal Guardian ☐Other:

If this consent is for a child who is a ward of the state (for example a foster child), please tell the study team immediately. The researchers may need to contact the IRBMED.

Reason subject is unable to sign for self:_____________________________________

____

Principal Investigator (or Designee):

I have given this research subject (or his/her legally authorized representative, if applicable) information about this study that I believe is accurate and complete. The subject has indicated that he or she understands the nature of the study and the risks and benefits of participating.

Name: ______________________________ Title:

Signature: ___________________________ Date of Signature:

Child assent 16-18 years old

University of Michigan Assent Form for Research

We want to tell you about a research study we are doing. Research is a way to learn more about something.

- The name of this study is: **Integrated structural, strength and mechanical contributions to ACL injury and knee osteoarthritis risk in the maturing knee joint** – Phase 3**.**
- The researchers are: **Scott McLean**, Ph.D., **Riann Palmieri-Smith**, Ph.D., ATC, **Catherine Brandon**, MD., **Jesal Parekh**, MS, **Jessica Deneweth, MS and Tyler Brown, MS**.

It is okay to ask questions about what we are telling you. You can circle or highlight things on this paper you want to know more about. If you don't understand something, just ask us. We want you to ask questions now and anytime later when you think of them.

We are working to find out what parts of knee injury prevention training programs actually work. Also, we are trying to find out how good these programs are when you participate in actual sports movements and how long the effects of the training last.

You are being asked to be in this research study because you currently may either play a sport where ACL injuries can often occur and are very good at performing the jumping and landing movements that we will be testing. If you're going to be in this study, **you must be female between 10 and 18 years old**, cannot have any previous history of a serious hip, knee or ankle injury or surgery; you cannot be currently be experiencing knee pain; you cannot suffer from a heart condition or be pregnant. **You must be willing to do 90 minutes total of jumping and landing movements on three different occasions, and be willing to take part in a six week training program where you are trained three times per week..** If you meet all of these qualifications, then you can be in the study. If you decide to be in this research and your parent or guardian says yes, this is what will happen:

- We will first put you into one six different training groups (Groups 1 – 6). Your training program will be based on which of these groups you are randomly put into.
- You will be asked to be a part of the training three times per week for six weeks, with each training session lasting between 60 and 90 minutes.
- You will be asked to train in the Injury Biomechanics Laboratory at the School of Kinesiology, The University of Michigan.
- There will be a number of trainers there each time to help you with the training and to explain what you have to do each time.
- Each of the six training groups will use different training techniques to try and improve your ability to land safely from a jump or pivoting movement.

- If you are put into the first training group (Group 1), you will be asked to take part in training that improves your strength, balance and coordination. You will be asked to perform a number of different movements on different surfaces and in different positions to help improve all of these things.
- If you are put into Group 2, you will be asked to take part in training that improves your coordination during fast movements and landings. You will be asked to perform a number of different movements and landings of two legs and then one leg in a number of different directions.
- If you are put into Group 3, you will be asked to take part in training that improves your muscle strength and power. You will be asked to lift weights that will help improve strength in your upper and lower body. You will start out with small weights and over time increase the amount of weight that you lift to improve your strength and power.
- If you are put into Group 4, you will be asked to take part in training that improves your speed. You will be asked to run a number of sprints over different distances. You will also run these sprints while we try and restrain you with large elastic bands. By doing this, we will improve both your running speed and your muscle strength.
- If you are put into Group 5, you will be asked to take part in training that uses all of the training techniques that we use for groups 1 – 4. You will asked to do some of the exercises from each of these above training groups so that you can improve your all around strength, speed and coordination.
- If you are put into Group 6, you will be asked to take part in no training for the six weeks. You will be allowed to perform your normal activities that you already do now.
- Apart from the training, we will also ask you to come to be tested three different times. The first time will be immediately before you take part in the training program. The second time will be immediately after the training program. The third time will be six weeks after the training program.
- Each time, you will come to the Injury Biomechanics Laboratory at the School of Kinesiology, The University of Michigan. This test will take about 90 minutes each time.
- When you come to the injury biomechanics lab, we will measure a number of different things. First, we will ask you to perform a number of jumps and landings, sometimes on two feet and sometimes on one foot.
- At first, we will ask you to perform these movements and let you know exactly which way to move. After this, we will ask you to perform these same movements without knowing which may to move until you are in the air. You will also have to perform these movements and choose which way to move while you are being fatigued.
- To make you fatigued, we will ask you to perform sets of 8 lower leg squats between each movement that you have to do.
- We will ask you to keep doing squats and movements over and over until you cannot do 3 squats in a row.
- During each movement, we will measure how much your joints are moving and how much force you feel in your joints. To do this, we will place a

number of small markers on your body with tape, just like the ones they use when making video games. These stick right on your skin and do not hurt at all.

- We will also measure how hard your muscles are working when you are jumping and landing by placing some small sensors on the skin over your muscles. We will use tape so that the sensors do not move when you are being tested. These sensors will not hurt you at all.
- We will then measure how strong your leg muscles are. You will be asked to sit in a chair and will have your legs strapped into a machine that can measure your muscle strength. Once you are strapped in, we will ask you to kick out and pull back your leg as hard and as fast as possible. After a five minute rest, we will ask you to try and hold your leg as still as possible while the machine tries to move it. This time, we will measure how hard your muscles are working to keep your leg still.
- You will also be asked to do two hopping tasks on one leg to determine how powerful and coordinated you are.
- You will first be asked to stand on one leg and hop forward as far as you can and land on the same leg. You will be asked to do this three times.
- You will then be asked to hop forward on one leg for 6 meters as fast as possible. You will also do this three times and your fastest time will be recorded.

Some of the things that happen in the research may hurt or could be scary. Some of these things are:

- You could hurt your knee joint or your muscles during the jumping and landing movements
- Some kids feel sick, really hot, or sore after they finish the muscle strength tests or the jumping and landing movements.
- Sometimes the questions we ask can make you feel embarrassed.

We do not know if you will be helped by being in this study. We may learn something that will help other children that may injure their knees and knee ligaments some day.

You don’t have to be in this study if you don’t want to. Nobody will be mad at you if you don’t want to try it. You can say okay now, and you can change your mind later. Just tell the researcher, your doctor or your parent or guardian if you want to stop at any time. Your doctor will still take care of you if you don’t want to be in the study.

Signatures

I have read this form or someone has read it to me. If I did not understand something, I asked the doctor or the assistant to explain it to me. I can always ask the doctor or the assistant a question about the study if I don't understand something. I will be given a copy of this form.

Please check one box:

☐ **YES,** I want to be in this study and I know I can change my mind later.

☐ **NO**, I do not want to be in this study.

Child's signature:

____

Printed Name:____

Date of Signature:______________________ Age:_______

****

The following should be completed by the study member conducting the assent process if the child agrees to be in the study. Check all that apply.

☐ The child is capable of reading and understanding the assent form and has signed above as documentation of assent to take part in this study.

☐ The child is not capable of reading the assent form, but the information was verbally explained to him/her. The child signed above as documentation of assent to take part in this study.

☐ The child had ample opportunity to have his or her questions answered.

Signature of person obtaining agreement*:*______________________________ Date ___________

Printed name of person obtaining agreement*:*______________________________

Child assent 10 – 15 years old

University of Michigan Assent Form for Research

We want to tell you about a research study we are doing. Research is a way to learn more about something.

- The name of this study is: **Integrated structural, strength and mechanical contributions to ACL injury and knee osteoarthritis risk in the maturing knee joint** – Phase 3**.**
- The researchers are: **Scott McLean**, Ph.D., **Riann Palmieri-Smith**, Ph.D., ATC, **Catherine Brandon**, MD., **Jesal Parekh**, MS, **Jessica Deneweth, MS and Tyler Brown, MS**.

It is okay to ask questions about what we are telling you. You can circle or highlight things on this paper you want to know more about. If you don’t understand something, just ask us. We want you to ask questions now and anytime later when you think of them.

We are working to find out what parts of training programs that say they can prevent knee injuries actually work. We are also trying to find out how good these training programs are when you are actually doing sports movements and how long the training is successful for.

You are being asked to be in this research study because you may either play a sport where knee injuries often occur and are very good at performing the jumping and landing movements that we will be testing. If you're going to be in this study, **you must be female between 10 and 18 years old**, cannot have any previous serious hip, knee or ankle injury or surgery; you cannot be currently have any knee pain; you cannot suffer from a heart condition or be pregnant. **You must be willing to do 90 minutes total of jumping and landing movements on three different test days, and be willing to take part six weeks of training where you are trained three times per week.** If you meet all of these criteria, then you can be in the study. If you decide to be in this research and your parent or guardian says yes, this is what will happen:

- We will first put you into one six different training groups (Groups 1 – 6). The training that you do will depend on which of these groups you are randomly put into.
- You will be asked to training three times per week for six weeks and each training session will go for 60 and 90 minutes.
- You will be asked to train in the Injury Biomechanics Laboratory at the School of Kinesiology, The University of Michigan.
- There will be a number of trainers there each time to help you with your training and to show you what you have to do each time.
- Each of the six training groups will train in a different way to try and help you to land safely from different types of jumping movements.

- If you are put into the first training group (Group 1), you will be asked to do training that improves how strong you are, how well you balance and how coordinated you are. You will be asked to do different movements on different surfaces and in different positions to help make all of these things better.
- If you are put into Group 2, you will be asked to do training that makes you more coordinated when you do fast movements and landings. You will be asked to do different movements and landings on two legs and then one leg in lots of different directions.
- If you are put into Group 3, you will be asked to do training that improves how strong and powerful you are. You will be asked to lift weights that will make you stronger in your arms and legs. You will start out with small weights and slowly increase the amount of weight that you lift as you train more.
- If you are put into Group 4, you will be asked to do training that improves how fast you are. You will be asked to run a lot of sprints over different distances. You will also run these sprints while we try and hold you back with large elastic bands. By doing this, we will improve how fast and strong you are.
- If you are put into Group 5, you will be asked to do training that uses all of the training that we use for groups 1 – 4. You will be asked to do some of the exercises from each training type so that you can get stronger, faster and more coordinated.
- If you are put into Group 6, you will be asked to do no training for the six weeks. You will be allowed to do your normal training that you already do now.
- Apart from training, we will also ask you to come to be tested three different times. The first time will be right before you start your training. The second time will be righty after the training. The third time will be six weeks after training.
- Each time, you will come to the Injury Biomechanics Laboratory at the School of Kinesiology, The University of Michigan. This test will take about 90 minutes each time.
- When you come to the injury biomechanics lab, we will measure lots of different things. First, we will ask you to do lots of jumps and landings, sometimes on two feet and sometimes on one foot.
- First, we will ask you to do these movements and tell you which way to move. Then, we will ask you to do these same movements without knowing which may to move until you already are in the air. You will also do these movements and choose which way to move while your muscles are tired.
- To make your muscles tired, we will ask you to do sets of 8 lower leg squats before each movement that you do.
- We will ask you to keep doing squats and movements over and over until you cannot do 3 squats in a row.
- During each movement, we will measure how much your joints move and how much force you feel in your joints. To do this, we will put small markers

on your body with tape, just like the ones they use when making video games. These stick right on your skin and do not hurt at all.

- We will also measure how hard your muscles are working when you are jumping and landing by placing some small sensors on your skin. We will use tape so that the sensors do not move when you are being tested. These sensors will not hurt you at all.
- We will then measure how strong your leg muscles are. You will be asked to sit in a chair and will have your legs strapped into a machine that can measure how strong you are. We will ask you to kick out and pull back your leg as hard and as fast as you can. After a five minute rest, we will ask you to try and hold your leg as still as possible while the machine tries to move it. This time, we will measure how hard your muscles are working to keep your leg still.
- You will also be asked to do two hopping movements on one leg to determine how powerful and coordinated you are.
- You will first be asked to stand on one leg and hop forward as far as you can and land on the same leg. You will be asked to do this three times.
- You will then be asked to hop forward on one leg for 6 meters as fast as possible. You will also do this three times and your fastest time will be recorded.

Some of the things that happen in the research may hurt or could be scary. Some of these things are:

- You could hurt your knee joint or your muscles during the jumping and landing movements
- Some kids feel sick, really hot, or sore after they finish the muscle strength tests or the jumping and landing movements.
- Sometimes the questions we ask can make you feel embarrassed.

We do not know if you will be helped by being in this study. We may learn something that will help other kids that may injure their knees some day.

You don’t have to be in this study if you don’t want to. Nobody will be mad at you if you don’t want to try it. You can say okay now, and you can change your mind later. Just tell the researcher, your doctor or your parent or guardian if you want to stop at any time. Your doctor will still take care of you if you don’t want to be in the study.

Signatures

I have read this form or someone has read it to me. If I did not understand something, I asked the doctor or the assistant to explain it to me. I can always ask the doctor or the assistant a question about the study if I don't understand something. I will be given a copy of this form.

Please check one box:

☐ **YES,** I want to be in this study and I know I can change my mind later.

☐ **NO**, I do not want to be in this study.

Child's signature:

____

Printed
Name:____

Date of Signature:_____________________ Age:_______

****
****

The following should be completed by the study member conducting the assent process if the child agrees to be in the study. Check all that apply.

☐ The child is capable of reading and understanding the assent form and has signed above as documentation of assent to take part in this study.

☐ The child is not capable of reading the assent form, but the information was verbally explained to him/her. The child signed above as documentation of assent to take part in this study.

☐ The child had ample opportunity to have his or her questions answered.

Signature of person obtaining agreement*:*______________________________ Date ___________

Printed name of person obtaining agreement*:*____

APPENDIX C

Recruitment materials

Training advertisement

KINESIOLOGY
studying movement

UNIVERSITY OF MICHIGAN

HEALTHY FEMALES WANTED TO PARTICIPATE IN A RESEARCH STUDY

Description of Research: Anterior cruciate ligament (ACL) injuries are common traumatic sports-related injuries that occur during abnormal or extreme landing or pivoting movements. These injuries are more frequent in women, and require lengthy rehabilitation, and extended periods away from sport. Currently, training programs aimed at reducing ACL injury risk exist and try to improve the way you land or pivot by increasing coordination and strength during sports landings. These programs do not appear to be working, however, since ACL injury rates have not been reduced. It may be that realistic sports scenarios compromise the improvements from training. Hence, the purpose of this study is to determine which components of typical ACL prevention training programs contribute to a reduction in ACL injury risk and how well the contributions hold up during sports participation. It is hoped that the results of this study will provide immediate benefits to current ACL injury prevention methods and prevent ACL injuries in everyone.

Do I qualify to participate? Participants must be healthy, physically active, and between the ages 10 -18. You must currently participate (either recreationally or within an organized team) in basketball, field hockey, soccer, lacrosse, or volleyball as you will be required to perform movements common to these sports. Pregnant females are not eligible to participate. Volunteers cannot have: (1) a history of previous knee injury or surgery, (2) recent injury to lower extremity, (3) pain in lower extremity prior to testing, or (4) extreme training/playing commitments.

Description of Participation: Participants will be asked to participate in 3 testing sessions that will last approximately 120 minutes each time. During each testing session, you will be asked to perform a series of single and double-leg jump landings. The testing sessions will be 6 weeks apart and the study will be a total of 13 weeks.

Where will the research take place? Volunteers will report for testing in the research laboratory of the Bone and Joint Injury Prevention and Rehabilitation Center located in MedSport at Domino Farms.

Will I be paid anything for participating in this study? You will receive $25.00 for your participation in each set of the three testing sessions. If you complete the entire study you will therefore receive a total of $75.

Who should I contact if I want to volunteer to participate?
Tyler Brown, MS, CSCS
Email: tynbrown@umich.edu
Phone: 509 338 5162

Research procedures

Testing Sessions

Participants will be asked to participate in 3 testing sessions. The testing sessions will each be separated by 6 weeks and will be conducted within Bone and Joint Injury Prevention and Rehabilitation Center located in MedSport at Domino Farms. Each session will last approximately 90 minutes and the total time of the study will be 13 weeks. During each testing session, the participant will have lower limb joint movements and forces, and muscle activity recorded during a series of single and double-leg jump landings. A more detailed description of each of the measures recorded during this session is provided below.

Lower Limb Movements and Forces

During each testing session, the participants will be required to perform a series of jump and land tasks. These tasks will include both double and single (left and right) leg landings. When they land, the participant will have to jump to the left, right or vertically as quickly as possible. They will be told which direction to jump by a series of lights or the experimenter (Figure 1). If L1 comes on, they will be required to land on the left foot only and jump quickly to the right. If L2 comes on, they will be required to land on the right foot only and jump quickly to the left. The double leg landings will be randomly initiated by the experimenter throughout the testing procedures and will require the participant to land on both feet and jump vertically as high as possible.

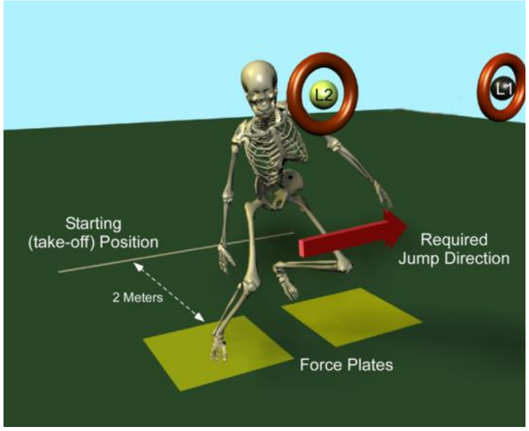

Figure 1: You will be asked to jump forward and after landing, move immediately in a specific

The participant will perform approximately 40 single leg landings, 20 anticipated and 20 unanticipated jump landings. The double leg landing trials will be performed at the start and finish of the single leg landing protocol and approximately after every 8 single leg landings for the duration of the testing.

During all movement tasks, the participant will have 28 reflective markers attached to their body, which, in conjunction with special high-speed video cameras, will allow us to measure their joint movements and forces. The markers will be attached directly to the skin using adhesive tape and will not cause any discomfort. As some markers are required to be attached to the thigh and pelvis, the participant will be asked to wear bicycle shorts and tight spandex shirt during all testing procedures.

Muscle Activity

We will also be collecting muscle electromyographic (EMG) data during the movements so we can determine how active the participant's muscles are. They will have 16 small EMG electrodes attached to the skin over various leg muscles, which will record their activity during each landing. In order to obtain a maximum signal from these electrodes, we will need to shave and lightly abrade (with plastic gauze) the skin where the electrode will be placed prior to cleaning it with alcohol. The participant may feel a brief stinging sensation when the alcohol is applied, but the electrodes will cause them no discomfort after this point.

APPENDIX D

Data collection materials

Subject information

Name:	**Date:**
Subject ID Number:	**Age:**
Height:	**Weight:**
Dominant Leg:	LT / RT
Training Group:	**Soccer Team:**
Contact Info:	

Leg Length	
RT	
LT	

Questionnaires	
Assent	Y / N
Consent	Y / N
Dominance	Y / N
Footedness	Y / N

Physical Activity	Y / N
Pre-participation	Y / N
Maturation	Y / N

Joint laxity

Subj. #:	**Pre**	**Post0**	**Post6**	**Date:**

		Relaxed			**Contracted**		
		1	**2**	**3**	**1**	**2**	**3**
Joint Laxity	**RT**						
	LT						

		Score	
Joint Mobility	**Hyperextension of the 5th finger:**	0 / 1	0 / 1
	Thumb opposition:	0 / 1	0 / 1
	Elbow Hyperextension:	0 / 1	0 / 1
	Knee Hyperextension:	0 / 1	0 / 1
	Trunk and Hip Flexion:	0 / 1	
	Hypermobile:	**Y / N**	

Physical performance

Subj. #:	**Pre**	**Post0**	**Post6**	**Date:**

Agility	**1**	**2**	**3**

Hop		**1**	**2**	**3**
	RT			
	LT			

Speed	**1**	**2**	**3**

Strength

Subj. #: **Pre** **Post0** **Post6**	**Date:**

Strength	**Knee**		**1**	**2**
	RT	Extension (+)		
		Flexion (-)		
	LT	Extension (-)		
		Flexion (+)		
	Hip			
	RT	Extension (-)		
		Flexion (+)		
	LT	Extension (+)		
		Flexion (-)		
	RT	Abduction (+)		
		Adduction (-)		
	LT	Abduction (+)		
		Adduction (-)		

Biomechanics

Subj. #:	**Pre**	**Post0**	**Post6**	**Date:**

MVC		**Kn. Ext.**	**Kn. Flx.**	**Hip Abd.**	**Plantar Flx.**
	RT				
	LT				
	Rest				

Balance	**Static:**	**1**	**2**	**3**
	Open			
	Closed			
	Dynamic:	**1**	**2**	**3**
	Forward			
	Medial			

Vertical		**1**	**2**	**3**
	Pre			
	Post			

Good Trials		**AN**	**UN**
	RT	1 2 3 4 5 6 7 8	1 2 3 4 5 6 7 8

	LT	1 2 3 4 5 6 7 8	1 2 3 4 5 6 7 8
	Vert	1 2 3 4 5 6 7 8	

Trial	**Condition**	**Leg**	**Success**	**Comments**
Static			G / B	
1	Vert	Both	G / B	
2	Vert	Both	G / B	
3	AN / UN	LT / RT	G / B	
4	AN / UN	LT / RT	G / B	
5	AN / UN	LT / RT	G / B	
6	AN / UN	LT / RT	G / B	
7	AN / UN	LT / RT	G / B	
8	AN / UN	LT / RT	G / B	
9	AN / UN	LT / RT	G / B	
10	AN / UN	LT / RT	G / B	
11	Vert	Both	G / B	
12	AN / UN	LT / RT	G / B	
13	AN / UN	LT / RT	G / B	
14	AN / UN	LT / RT	G / B	
15	AN / UN	LT / RT	G / B	
16	AN / UN	LT / RT	G / B	
17	AN / UN	LT / RT	G / B	
18	AN / UN	LT / RT	G / B	
19	AN / UN	LT / RT	G / B	

20	Vert	Both	G / B	
21	AN / UN	LT / RT	G / B	
22	AN / UN	LT / RT	G / B	
23	AN / UN	LT / RT	G / B	
24	AN / UN	LT / RT	G / B	
25	AN / UN	LT / RT	G / B	
26	AN / UN	LT / RT	G / B	
27	AN / UN	LT / RT	G / B	
28	AN / UN	LT / RT	G / B	
29	Vert	Both	G / B	
30	AN / UN	LT / RT	G / B	
31	AN / UN	LT / RT	G / B	
32	AN / UN	LT / RT	G / B	
33	AN / UN	LT / RT	G / B	
34	AN / UN	LT / RT	G / B	
35	AN / UN	LT / RT	G / B	
36	AN / UN	LT / RT	G / B	
37	AN / UN	LT / RT	G / B	
38	Vert	Both	G / B	
39	AN / UN	LT / RT	G / B	
40	AN / UN	LT / RT	G / B	
41	AN / UN	LT / RT	G / B	
42	AN / UN	LT / RT	G / B	

43	AN / UN	LT / RT	G / B	
44	AN / UN	LT / RT	G / B	
45	AN / UN	LT / RT	G / B	
46	AN / UN	LT / RT	G / B	
47	Vert	Both	G / B	
48	AN / UN	LT / RT	G / B	
49	AN / UN	LT / RT	G / B	
50	AN / UN	LT / RT	G / B	
51	AN / UN	LT / RT	G / B	
52	AN / UN	LT / RT	G / B	
53	AN / UN	LT / RT	G / B	
54	AN / UN	LT / RT	G / B	
55	AN / UN	LT / RT	G / B	
56	Vert	Both	G / B	
57	Vert	Both	G / B	
58			G / B	
59			G / B	
60			G / B	
61			G / B	
62			G / B	
63			G / B	
64			G / B	
65			G / B	

66			G / B	
67			G / B	
68			G / B	
69			G / B	
70			G / B	

Pre-participation Questionnaire

1. Have you suffered an injury to your hip, knee, or ankle in the past 6 months?

YES NO

If yes, please describe: ____

2. Have you undergone surgery to your hip, knee, or ankle?

YES NO

If yes, please describe: ____

3. Are you currently undergoing rigorous physical training or do you plan to start a rigorous training program in the next 3 months?

YES NO

If yes, please describe: ____

4. Are you currently experiencing knee pain?

YES NO

5. Are you currently suffering from or have you ever suffered from a heart condition?

YES NO

If yes, please describe: ____

6. Do you know of any reason why you cannot participate in this study?

YES NO

If yes, please explain: ____

I certify that the information I provided above is accurate.

Subject's Signature: ___________________________ Date: ______________

Subject's Name (Print): _________________________

Parent/Legal Guardian Signature: ___________________ Date: __________

Parent/Legal Guardian Name (Print): _________________________

Footedness Questionnaire

Instructions: Answer each of the following questions as best you can. If you always use one foot to perform the described activity, circle **Ra** or **La** (for right always or left always). If you usually use one foot circle **Ru** or **Lu**, as appropriate. If you use both feet equally often, circle **Eq**.

Please do not simply circle one answer for all questions, but imagine yourself performing each activity in turn, and then mark the appropriate answer. If necessary, stop and pantomime the activity.

1. Which foot would you use to kick a stationary ball at a target straight in front of you?

La **Lu** **Eq** **Ru** **Ra**

2. If you had to stand on one foot, which foot would it be?

La **Lu** **Eq** **Ru** **Ra**

3. Which foot would you use to smooth sand at the beach?

La **Lu** **Eq** **Ru** **Ra**

4. If you had to step up onto a chair, which foot would you place on the chair first?

La **Lu** **Eq** **Ru** **Ra**

5. Which foot would you use to stomp on a fast-moving bug?

La **Lu** **Eq** **Ru** **Ra**

6. If you were to balance on one foot on a railway track, which foot would you use?

La **Lu** **Eq** **Ru** **Ra**

7. If you wanted to pick up a marble with your toes, which foot would you use?

La **Lu** **Eq** **Ru** **Ra**

8. If you had to hop on one foot, which foot would you use?

La **Lu** **Eq** **Ru** **Ra**

9. Which foot would you use to help push a shovel into the ground?

La **Lu** **Eq** **Ru** **Ra**

10. During relaxed standing, people initially put most of their weight on one foot, leaving the other leg slightly bent. Which foot do you put most of your weight on first?

La **Lu** **Eq** **Ru** **Ra**

11. Is there any reason (i.e. injury) why you have changed your foot preference for any of the above activities?

Yes **No**

12. Have you ever been given special training or encouragement to use a particular foot for certain activities?

Yes **No**

13. If you have answered YES for either question 11 or 12, please explain:

Pubertal Maturation Observational Scale

Female Characteristic Checklist

_____ The adolescent has grown 3 to 3.5 inches in the past 6 months or is past this growth spurt.

_____ The adolescent has begun breast development.

_____ The adolescent has begun menarche.

_____ The adolescent has evidence of darker underarm hair or shaves.

_____ The adolescent has evidence of darker hair on her legs or shaves.

_____ The adolescent's calves are becoming defined.

_____ The adolescent has evidence of acne.

_____ There was evidence of sweating after physical activities.

Male Characteristic Checklist

_____ The adolescent has evidence of darkening of facial hair or shaves.

_____ The adolescent's voice has gotten deeper or is currently breaking.

_____ The adolescent has grown 3 to 4 inches in the past 6 months or is past the growth spurt.

_____ The adolescent has darker hair on his legs.

_____ The adolescent's biceps are becoming defined.

_____ The adolescent's calves are becoming defined.

_____ The adolescent has evidence of acne.

_____ There was evidence of sweating after physical activities.

_____ There is darkened underarm hair.

Key:

+ characteristic is present
_ characteristic is absent

Scoring Criteria for Males and Females:

STAGES NUMBER OF "+"
Prepuberty 1 or less
Midpubertal 4 or 5; growth spurt essential
Postpubertal at least 6; growth spurt completed

Physical Activity Rating Questionnaire

In the table below, write down the number of times (on each day) that you participated in vigorous and moderate physical activities over the last seven days. Examples of vigorous activities would be running, playing sport and training for sport. Examples of moderate activities would be walking or slow cycling. Only include activities if they were undertaken continuously for at least 20 minutes.

	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7
Vigorous Activity							
Moderate Activity							

Key:

Physical Activity Score (PAS) = average frequency x 20 x 4 (moderate) + average frequency x 20 x 7.5 (vigorous).

Scoring Criteria:

Low: PAS < 400

Moderate: 400 ≤ PAS < 560

High: PAS ≥ 560

APPENDIX E

Supplemental Data

Table E.1. Competitive Athlete Subject Demographic Data

Subj ID	Training Group	Dominant Limb	Age (yrs)	Height (m)	Weight (kg)	PMOS	PAS Score	Joint Laxity
1	4	0	13	1.59	47.7	Midpubertal	289	n/a
7	4	0	13	1.52	40.0	Midpubertal	96	n/a
8	4	0	13	1.65	52.7	Midpubertal	114	n/a
12	4	0	15	1.70	60.5	Postpubertal	519	n/a
14	4	0	13	1.56	43.0	Postpubertal	744	n/a
15	4	0	13	1.56	42.0	Postpubertal	744	n/a
16	4	0	13	1.61	50.9	Postpubertal	675	n/a
34	3	0	15	1.66	68.2	Postpubertal	193	5.5
35	2	0	16	1.63	62.0	Postpubertal	386	2
36	2	0	15	1.73	57.3	Postpubertal	479	3
37	2	0	16	1.70	80.5	Postpubertal	579	1.5
38	1	0	15	1.57	52.3	Postpubertal	69	6.5
39	1	0	14	1.60	49.1	Midpubertal	246	3
40	1	0	14	1.57	46.4	Postpubertal	126	7
41	1	0	16	1.63	50.0	Midpubertal	40	4
43	1	0	14	1.63	39.1	Postpubertal	34	5.5
45	2	0	15	1.52	49.3	Postpubertal	707	2.5
46	1	0	14	1.75	67.3	Postpubertal	99	3.5
47	1	0	15	1.77	63.0	Postpubertal	321	1.5
49	1	0	14	1.58	46.4	Midpubertal	343	8
50	3	0	15	1.65	68.4	Postpubertal	46	4
51	1	0	14	1.71	53.2	Postpubertal	468	35
52	1	0	14	1.61	50.5	Postpubertal	433	2
53	3	0	14	1.61	53.4	Postpubertal	210	2.5
54	4	0	15	1.61	43.8	Postpubertal	94	4
55	3	0	15	1.63	59.5	Postpubertal	161	1.5
59	2	0	15	1.70	54.8	Postpubertal	654	3
60	3	0	15	1.66	50.5	Postpubertal	171	2
61	3	1	15	1.61	63.6	Postpubertal	179	2.5
62	3	0	15	1.63	58.4	Midpubertal	113	1
63	3	0	16	1.68	76.4	Postpubertal	165	2.5
64	3	0	14	1.63	69.1	Postpubertal	137	5
65	3	0	15	1.63	49.3	Postpubertal	20	4.5
67	3	0	15	1.64	50.9	Postpubertal	26	2.5
68	3	0	14	1.64	55.0	Postpubertal	63	4.5
71	2	0	15	1.70	54.8	Postpubertal	283	5

Table E.1. cont'd

Subj ID	Training Group	Dominant Limb	Age (yrs)	Height (m)	Weight (kg)	PMOS	PAS Score	Joint Laxity
74	3	0	14	1.60	50.5	Postpubertal	64	4
76	2	0	15	1.65	73.2	Postpubertal	n/a	2
78	4	0	15	1.64	65.2	Postpubertal	482	5.5
80	4	0	18	1.68	63.9	Postpubertal	601	4.5
81	4	0	18	1.70	62.0	Postpubertal	659	5
82	4	18	18	1.69	70.0	Postpubertal	680	2
83	4	18	18	1.60	59.1	Postpubertal	595	7

Table E.2. Recreational Athlete Subject Demographic Data

Subj ID	Training Group	Dominant Limb	Age (yrs)	Height (m)	Weight (kg)	Tegner Score
1	1	0	19	1.55	50.0	5
2	1	0	18	1.57	50.0	6
3	1	0	18	1.60	59.1	8
4	1	0	21	1.60	70.5	5
6	1	0	21	1.60	56.8	5
7	1	0	19	1.73	61.4	5
9	1	0	19	1.63	47.7	5
11	1	0	18	1.63	65.9	6
14	1	0	22	1.65	54.5	6
15	1	0	19	1.57	70.5	5
16	1	0	19	1.73	63.6	7
17	1	0	20	1.63	59.1	6
18	2	0	18	1.75	54.5	6
19	2	0	19	1.65	68.2	5
20	2	0	19	1.63	54.5	5
21	2	0	18	1.60	54.5	6
22	2	0	20	1.75	63.6	6
23	1	0	20	1.68	65.9	6
24	1	0	18	1.73	65.9	9
25	1	0	18	1.63	54.5	5
26	1	0	18	1.68	63.6	6
33	1	0	18	1.65	63.6	6
35	1	0	20	1.65	75.0	5
36	1	0	18	1.55	50.0	6
38	2	0	19	1.57	59.1	6
40	1	0	21	1.68	59.1	6
42	2	0	21	1.63	65.9	6
44	2	0	21	1.75	63.6	6
45	2	0	19	1.63	61.4	7
46	2	0	22	1.63	52.3	7
49	2	0	19	1.63	52.3	5
50	2	0	15	1.70	60.5	n/a
51	2	0	15	1.61	43.8	n/a

Table E.3. Mean knee kinematic, kinetic and muscle activation data during unilateral landings for Aim 1.

Subj ID	Training Group	Knee Flex. Angle (deg)	Knee Abd. Angle (deg)	Knee Flex. Moment (N/kg/m)	Knee Abd. Moment (N/kg/m)	Knee Ant. Joint Reaction (N/kg of BW)	Vastus Lateralis (Norm. RMS)	Rectus Femoris (Norm. RMS)	Lat. Ham. (Norm. RMS)	Med. Ham. (Norm. RMS)
34	3	-58.79	-3.93	1.47	0.28	-0.36	2.54	0.22	0.27	0.55
35	2	-61.57	-7.94	1.5	0.67	0.24	1.09	0.46	0.94	0.61
36	2	-62.02	-3.81	1.57	0.34	-0.18	1.41	0.55	0.32	0.80
38	1	-69.75	-3.42	1.42	0.26	-0.61	0.48	0.21	0.13	0.13
39	1	-55.67	-0.32	1.56	0.42	-0.34	1.03	0.65	0.85	0.78
40	1	-65.34	-4.54	1.52	0.35	0.94	1.42	0.54	0.24	0.22
41	1	-51.18	-2.82	1.63	0.42	0.06	1.11	0.36	0.43	0.65
43	1	-75.54	-3.35	1.37	0.57	1.35	1.97	0.72	0.86	0.76
49	1	-61.94	-0.44	1.36	0.48	0.77	0.64	0.30	0.49	0.34
50	3	-65.47	-6.77	1.54	0.36	0.58	1.22	0.59	0.28	0.32
51	1	-40.18	-3.57	1.1	0.54	1.24	1.27	0.59	0.74	0.80
52	1	-48.85	-7.43	1.2	0.59	1.21	0.69	0.52	0.21	0.32
53	3	-66.81	-1.41	1.54	0.19	0.1	1.14	0.39	0.71	0.45
54	4	-60.62	-3.94	1.48	0.23	0.51	2.29	0.56	0.29	0.19
59	2	-58.55	-2.77	1.32	0.17	0.6	0.97	0.26	0.58	0.49
60	3	-76.54	-7.23	2.31	0.68	-1.02	1.80	0.36	0.39	0.21
61	3	-63.38	-3.12	1.61	0.43	-0.36	0.34	0.16	0.12	0.25
62	3	-60.53	-0.99	1.74	0.32	0.2	0.78	0.20	0.26	0.65
63	3	-64.15	-6.80	1.16	0.27	2.31	0.93	0.79	0.26	0.12
64	3	-58.67	-3.15	1.2	0.16	1.09	1.70	0.54	1.38	0.50
65	3	-53.24	-1.28	1.47	0.31	-0.16	1.80	0.28	0.42	0.61
67	3	-61.43	-2.34	1.53	0.44	-0.21	0.45	0.21	0.16	0.32
68	3	-72.41	-0.69	1.59	0.36	-0.05	1.56	0.75	0.32	0.54
74	3	-65.44	-7.12	2.01	0.47	0.72	2.44	0.37	0.31	0.98

Table E.3. cont'd

Subj ID	Training Group	Knee Flex. Angle (deg)	Knee Abd. Angle (deg)	Knee Flex. Moment (N/kg/m)	Knee Abd. Moment (N/kg/m)	Knee Ant. Joint Reaction (N/kg of BW)	Vastus Lateralis (Norm. RMS)	Rectus Femoris (Norm. RMS)	Lat. Ham. (Norm. RMS)	Med. Ham. (Norm. RMS)
45	2	-61.76	-5.69	1.6	0.34	-0.96	1.79	0.24	0.17	0.46
46	1	-50.44	-1.94	1.41	0.39	-0.58	1.93	0.64	0.34	0.38
47	1	-50.30	-4.44	1.61	0.21	0.24	0.97	0.56	0.38	0.54
55	3	-53.12	-1.73	1.8	0.48	0.18	1.47	0.52	0.40	0.33
71	4	-45.67	-0.46	1.96	0.57	0.17	1.97	0.29	0.67	0.35
78	2	-60.72	0.66	1.17	0.43	0.99	0.80	1.00	0.22	0.13

AIM 1 STATISTICAL OUTPUT

Variables Entered/Removed[a]

Model	Variables Entered	Variables Removed	Method
1	Pre_RRF_An	.	Stepwise (Criteria: Probability-of-F-to-enter <= .050, Probability-of-F-to-remove >= .100).
2	Pre_RVL_An	.	Stepwise (Criteria: Probability-of-F-to-enter <= .050, Probability-of-F-to-remove >= .100).

a. Dependent Variable: PreRtKneeXAnTrq

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.391[a]	.153	.122	.24512
2	.523[b]	.273	.219	.23119

a. Predictors: (Constant), Pre_RRF_An

b. Predictors: (Constant), Pre_RRF_An, Pre_RVL_An

ANOVA[c]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	.303	1	.303	5.048	.033[a]
	Residual	1.682	28	.060		
	Total	1.986	29			
2	Regression	.543	2	.271	5.076	.013[b]
	Residual	1.443	27	.053		
	Total	1.986	29			

a. Predictors: (Constant), Pre_RRF_An

b. Predictors: (Constant), Pre_RRF_An, Pre_RVL_An

c. Dependent Variable: PreRtKneeXAnTrq

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	1.752	.110		15.864	.000
	Pre_RRF_An	-.492	.219	-.391	-2.247	.033
2	(Constant)	1.564	.137		11.415	.000
	Pre_RRF_An	-.525	.207	-.418	-2.538	.017
	Pre_RVL_An	.153	.072	.348	2.116	.044

a. Dependent Variable: PreRtKneeXAnTrq

Excluded Variables[c]

Model		Beta In	t	Sig.	Partial Correlation	Collinearity Statistics
						Tolerance
1	Pre_RVL_An	.348[a]	2.116	.044	.377	.994
	Pre_RLH_An	-.105[a]	-.585	.563	-.112	.971
2	Pre_RLH_An	-.169[b]	-1.001	.326	-.193	.944

a. Predictors in the Model: (Constant), Pre_RRF_An

b. Predictors in the Model: (Constant), Pre_RRF_An, Pre_RVL_An

c. Dependent Variable: PreRtKneeXAnTrq

Variables Entered/Removed[a]

Model	Variables Entered	Variables Removed	Method
1	Pre_RRF_An	.	Stepwise (Criteria: Probability-of-F-to-enter <= .050, Probability-of-F-to-remove >= .100).

a. Dependent Variable: PreRtAntShrAn

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.516[a]	.266	.240	.65080

a. Predictors: (Constant), Pre_RRF_An

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	4.300	1	4.300	10.152	.004[a]
	Residual	11.859	28	.424		
	Total	16.159	29			

a. Predictors: (Constant), Pre_RRF_An
b. Dependent Variable: PreRtAntShrAn

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-.565	.293		-1.928	.064
	Pre_RRF_An	1.851	.581	.516	3.186	.004

a. Dependent Variable: PreRtAntShrAn

Excluded Variables[b]

Model		Beta In	t	Sig.	Partial Correlation	Collinearity Statistics
						Tolerance
1	Pre_RVL_An	-.142[a]	-.870	.392	-.165	.994
	Pre_RLH_An	.167[a]	1.018	.318	.192	.971

a. Predictors in the Model: (Constant), Pre_RRF_An

b. Dependent Variable: PreRtAntShrAn

Table E.4. Mean Initial Contact Hip and Knee Kinematic Data for Bilateral and Unilateral Landings at Both Pre- and Post-Training Time Points for Aim 2.

	Pre-Training								**Post-Training**							
	Bilateral				**Unilateral**				**Bilateral**				**Unilateral**			
	Hip		**Knee**		**Hip**		**Knee**		**Hip**		**Knee**		**Hip**		**Knee**	
Subj ID	**Flx**	**Add**	**Flx**	**Abd**	**Flx**	**Add**	**Flx**	**Abd**	**Flx**	**Add**	**Flx**	**Abd**	**Flx**	**Add**	**Flx**	**Abd**
1	46.40	6.40	-32.60	-8.14	32.12	-5.32	-21.72	-11.66	46.70	6.00	-28.30	-3.65	39.46	-9.53	-21.72	-5.73
2	42.00	3.32	-29.00	-10.80	33.01	-12.31	-21.36	-10.67	42.70	1.31	-28.60	-13.70	33.18	-14.01	-12.56	-10.02
3	49.60	3.07	-19.70	-6.06	35.18	-4.37	-18.15	-7.86	40.60	-1.38	-19.70	-7.98	35.25	-5.42	-10.24	-5.34
4	48.60	0.93	-28.70	-3.88	32.37	-11.65	-13.22	-2.96	35.10	-8.01	-18.70	-0.02	40.15	-11.49	-5.52	0.06
6	42.40	4.17	-22.20	-5.36	34.11	-3.34	-15.12	-4.70	43.70	3.57	-20.90	-3.14	35.69	0.51	-15.44	-4.56
7	34.90	1.37	-24.60	-0.96	37.16	-8.37	-20.18	-2.92	38.90	2.01	-24.80	-1.42	32.16	-10.46	-20.02	-4.70
9	26.90	4.37	-10.00	-5.46	20.94	-2.86	-13.13	-6.08	32.20	1.12	-48.90	-13.80	24.88	-9.61	-11.08	-5.33
11	32.40	-4.08	-23.80	2.56	34.66	-8.07	-18.97	0.15	45.10	-0.72	-24.70	-3.10	36.80	-8.53	-27.36	-3.98
14	51.40	-2.32	-28.60	-5.21	44.61	-6.65	-26.11	-5.78	42.30	0.44	-23.30	-6.34	41.56	-4.18	-22.54	-6.84
15	33.30	7.16	-27.00	-7.27	27.58	-8.83	-10.75	-4.81	44.70	3.03	-25.80	-5.91	34.09	-8.42	-14.42	-5.89
16	53.50	1.77	-29.40	-4.51	39.79	-5.50	-23.07	-6.43	46.70	2.51	-21.50	-5.21	43.34	-3.81	-25.87	-6.45
17	19.60	-6.20	-13.40	-0.04	18.17	-14.36	-13.22	-1.13	31.20	-0.04	-26.80	-6.41	24.81	-17.92	-13.49	-3.59
18	44.50	3.86	-29.10	-2.94	32.79	-4.86	-21.90	-4.60	41.50	1.80	-30.40	-8.11	35.06	-7.39	-12.67	-5.66
19	42.80	6.74	-34.70	-7.16	37.66	-8.59	-16.77	-4.98	47.80	5.30	-29.90	0.26	42.54	-7.85	-19.83	-0.71
20	39.90	-3.95	-31.20	-12.00	28.13	-11.01	-21.05	-10.82	33.40	2.50	-18.60	-4.27	28.78	-11.18	-12.99	-7.66
21	45.50	5.67	-16.00	-2.64	33.09	-14.56	-19.44	-4.93	48.60	0.29	-19.60	-3.02	38.72	-12.00	-16.55	-4.90
22	52.00	4.75	-28.10	-5.26	22.43	-2.57	-19.06	-5.20	47.40	4.18	-27.20	-8.21	46.56	-5.32	-13.89	-6.79
23	50.90	-1.59	-34.80	-0.11	42.52	-3.46	-15.86	-1.02	44.60	-6.44	-39.90	2.30	38.51	-6.92	-15.54	0.57
24	41.60	-1.49	-19.40	-3.63	27.18	-9.94	-5.94	-2.31	45.90	2.28	-21.70	-2.35	31.90	-6.99	-3.16	-0.47
25	46.60	0.68	-29.50	-4.97	37.66	-8.29	-13.85	-1.66	37.80	-2.25	-20.00	-1.72	29.95	-18.04	-7.60	-0.65
26	43.70	2.24	-28.60	-9.30	37.76	-4.45	-23.92	-8.99	52.90	-2.66	-35.30	-2.90	39.87	-4.00	-22.66	-4.19
33	42.70	3.43	-20.20	-7.84	30.48	-6.74	-13.91	-6.56	50.00	16.70	-30.50	-7.84	37.60	2.77	-12.49	-5.55

Table E.4. cont'd

	Pre-Training								**Post-Training**							
	Bilateral				**Unilateral**				**Bilateral**				**Unilateral**			
	Hip		**Knee**		**Hip**		**Knee**		**Hip**		**Knee**		**Hip**		**Knee**	
Subj ID	**Flx**	**Add**	**Flx**	**Abd**	**Flx**	**Add**	**Flx**	**Abd**	**Flx**	**Add**	**Flx**	**Abd**	**Flx**	**Add**	**Flx**	**Abd**
35	44.90	2.43	-29.80	-3.04	26.40	-19.38	-20.81	-5.27	47.20	-0.49	-19.70	-7.62	39.88	-12.72	-17.63	-10.09
36	41.40	1.07	-27.80	-12.80	21.58	-8.41	-10.94	-6.67	34.60	-0.05	-18.00	-6.77	24.69	-7.65	-4.12	-4.86
38	42.10	-11.20	-5.93	-2.85	37.34	-8.33	-12.27	-3.93	43.40	3.57	-42.40	-6.15	22.78	-12.05	-0.95	-1.44
40	42.60	-1.98	-43.50	-4.33	35.37	-15.13	-26.63	-5.64	43.20	-1.00	-38.40	-10.70	35.92	-12.01	-23.68	-8.02
42	31.30	-2.51	-7.81	-3.63	22.54	-12.74	3.75	-3.44	34.70	0.34	-9.48	-7.65	21.99	-9.60	2.46	-6.01
44	47.90	0.55	-27.20	-6.75	39.82	-4.71	-16.11	-4.59	44.20	3.88	-23.50	-6.31	42.42	-0.82	-18.97	-6.52
45	41.70	-5.12	-26.70	-3.65	34.77	-10.59	-15.59	-4.73	40.10	-0.16	-23.10	-9.87	33.28	-9.58	-14.83	-9.51
46	32.20	1.22	-21.70	-12.40	24.46	-7.00	-8.09	-7.97	28.50	1.25	-20.30	-6.51	27.74	-1.61	-11.49	-6.03
49	34.70	0.39	-17.90	-3.23	35.89	-5.19	-10.89	-2.83	39.20	5.94	-44.10	-9.64	35.03	-12.16	-5.59	-0.02
50	46.00	2.07	-25.93	-7.44	27.05	-6.61	-10.20	-5.74	38.24	-3.24	-17.56	-5.32	46.00	2.07	-25.93	-7.44
51	27.74	-8.54	-22.86	-2.39	26.27	-13.69	-14.01	-2.02	39.80	-11.05	-28.91	-2.67	27.74	-8.54	-22.86	-2.39

Table E.5. Mean Peak Stance (0% - 50%) Phase Hip and Knee Kinematic Data for Bilateral and Unilateral Landings at Both Pre- and Post-Training Time Points for Aim 2.

	Pre-Training								**Post-Training**							
	Bilateral				**Unilateral**				**Bilateral**				**Unilateral**			
	Hip		**Knee**		**Hip**		**Knee**		**Hip**		**Knee**		**Hip**		**Knee**	
Subj ID	**Flx**	**Add**	**Flx**	**Abd**	**Flx**	**Add**	**Flx**	**Abd**	**Flx**	**Add**	**Flx**	**Abd**	**Flx**	**Add**	**Flx**	**Abd**
1	57.20	8.22	-88.90	-17.10	38.28	7.66	-67.50	-17.03	72.60	6.07	-97.70	-6.23	46.92	2.99	-65.02	-7.73
2	58.30	7.46	-86.30	-24.60	40.42	-2.19	-67.46	-26.45	66.20	7.39	-90.40	-27.10	45.38	-7.82	-61.23	-24.72
3	66.40	3.81	-100.00	-16.80	43.78	5.42	-59.97	-19.62	48.00	5.50	-76.60	-21.00	41.75	-0.42	-52.89	-15.52
4	49.60	7.59	-77.30	-13.00	36.04	-5.07	-55.58	-8.62	40.00	4.76	-68.40	-1.37	47.95	-1.42	-50.12	-0.33
6	72.00	9.05	-97.60	-20.10	46.65	6.87	-60.66	-16.63	72.60	7.20	-93.70	-12.00	45.89	5.29	-55.23	-11.32
7	52.60	5.28	-83.10	-9.43	42.55	-6.39	-58.89	-9.36	55.70	6.98	-78.50	-14.10	38.84	-8.66	-62.77	-12.78
9	44.20	7.89	-67.90	-22.70	28.65	3.75	-60.01	-20.60	42.90	2.52	-70.90	-19.40	33.11	1.16	-59.80	-21.46
11	40.80	-0.24	-79.00	-2.43	45.89	1.34	-71.01	-1.03	52.00	2.79	-83.40	-11.80	43.57	-2.00	-77.11	-13.26
14	55.40	0.42	-74.50	-18.70	46.45	0.22	-62.34	-15.96	51.40	2.62	-67.60	-22.90	44.17	1.01	-57.67	-18.61
15	50.40	7.79	-78.80	-11.20	32.94	-2.15	-61.02	-11.47	60.90	5.89	-86.90	-11.30	40.02	0.88	-69.21	-14.06
16	63.80	4.56	-81.30	-9.52	51.80	1.95	-61.46	-12.51	58.10	5.70	-75.90	-14.00	51.04	5.19	-65.02	-13.57
17	38.60	5.14	-83.40	-9.86	25.84	0.21	-64.64	-6.27	45.50	8.23	-79.40	-16.10	32.26	-7.96	-62.18	-14.87
18	57.20	4.99	-76.30	-5.46	36.31	3.04	-52.43	-9.02	63.30	2.75	-66.40	-18.30	39.02	0.97	-52.38	-15.66
19	52.30	11.80	-82.20	-16.00	47.95	5.46	-59.52	-13.20	48.30	8.21	-62.00	-0.88	46.74	-0.92	-62.14	-4.06
20	56.70	0.38	-96.10	-24.40	28.13	-6.34	-65.65	-21.62	52.50	6.49	-76.40	-15.70	33.75	1.50	-60.30	-13.01
21	53.50	7.04	-68.00	-9.30	33.75	-6.47	-50.77	-9.09	56.30	4.76	-62.30	-11.90	39.38	-1.23	-58.95	-12.12
22	53.80	9.05	-66.90	-18.00	47.84	8.39	-63.18	-17.57	51.90	11.80	-66.80	-17.00	48.83	9.93	-53.15	-12.38
23	67.40	6.93	-87.70	-16.70	48.47	10.60	-64.49	-11.43	62.50	-1.49	-100.00	-11.60	49.63	7.70	-68.74	-4.54
24	50.60	4.74	-68.80	-12.60	32.23	1.49	-46.40	-7.53	47.00	5.60	-64.80	-13.90	34.22	2.88	-41.10	-7.71
25	48.80	4.82	-73.50	-20.90	38.62	3.32	-57.94	-10.75	53.00	2.01	-75.40	-11.90	42.49	-3.61	-51.76	-3.45
26	47.40	7.47	-81.60	-25.50	37.76	4.79	-57.42	-19.84	68.70	0.92	-96.30	-15.30	40.94	5.41	-56.98	-10.95
33	75.10	9.11	-96.70	-19.10	38.35	1.56	-61.59	-18.78	71.40	17.20	-89.10	-13.40	49.18	13.59	-60.90	-13.80

Table E.5. cont'd

	Pre-Training								Post-Training							
	Bilateral				Unilateral				Bilateral				Unilateral			
	Hip		Knee		Hip		Knee		Hip		Knee		Hip		Knee	
Subj ID	**Flx**	**Add**	**Flx**	**Abd**	**Flx**	**Add**	**Flx**	**Abd**	**Flx**	**Add**	**Flx**	**Abd**	**Flx**	**Add**	**Flx**	**Abd**
35	48.10	5.03	-65.30	-3.04	26.40	-13.66	-54.62	-5.41	52.70	5.67	-65.00	-17.00	41.01	-12.21	-51.84	-15.42
36	52.90	7.26	-85.20	-24.50	33.63	-3.66	-60.58	-19.85	66.30	5.45	-95.30	-19.50	38.49	-0.58	-62.40	-15.32
38	63.00	12.00	-65.60	-19.10	43.13	-0.13	-50.43	-5.80	54.40	4.95	-60.80	-11.90	33.37	-1.59	-43.08	-10.71
40	52.10	3.18	-95.60	-12.90	42.68	0.39	-63.37	-13.58	50.80	1.06	-83.70	-20.40	43.12	2.39	-62.57	-19.68
42	45.60	2.66	-66.30	-9.90	34.93	0.34	-49.92	-7.10	47.30	3.89	-68.40	-20.00	29.10	-1.52	-46.31	-18.00
44	62.00	8.23	-95.60	-16.90	46.57	9.37	-56.30	-12.08	52.00	8.67	-73.50	-19.90	43.00	6.14	-50.65	-15.19
45	42.40	3.75	-64.80	-11.80	37.85	-2.44	-58.49	-11.21	40.10	5.97	-53.60	-20.00	38.32	1.86	-58.34	-20.45
46	58.50	3.06	-88.80	-30.90	28.49	3.96	-56.13	-29.70	54.70	7.48	-88.70	-23.60	32.94	7.25	-59.90	-20.12
49	46.70	11.70	-70.10	-7.25	37.48	3.29	-43.68	-4.17	47.80	9.23	-60.90	-16.00	40.09	1.42	-47.22	-8.40
50	63.39	18.85	-87.73	-20.47	30.01	14.57	-47.69	-14.51	59.54	9.50	-80.21	-28.29	24.79	8.30	-44.59	-16.22
51	31.26	-7.73	-63.87	-8.57	31.46	-9.44	-62.23	-6.50	44.85	-9.50	-77.05	-8.79	32.89	-7.93	-68.27	-5.78

AIM 2 STATISTICAL OUTPUT

Initial Contact Hip Flexion:

Tests of Within-Subjects Effects

Measure:MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Movement	Sphericity Assumed	2063.981	1	2063.981	153.201	.000	.832	153.201	1.000
	Greenhouse-Geisser	2063.981	1.000	2063.981	153.201	.000	.832	153.201	1.000
	Huynh-Feldt	2063.981	1.000	2063.981	153.201	.000	.832	153.201	1.000
	Lower-bound	2063.981	1.000	2063.981	153.201	.000	.832	153.201	1.000
Movement * Group	Sphericity Assumed	1.748	1	1.748	.130	.721	.004	.130	.064
	Greenhouse-Geisser	1.748	1.000	1.748	.130	.721	.004	.130	.064
	Huynh-Feldt	1.748	1.000	1.748	.130	.721	.004	.130	.064
	Lower-bound	1.748	1.000	1.748	.130	.721	.004	.130	.064
Error(Movement)	Sphericity Assumed	417.644	31	13.472					
	Greenhouse-Geisser	417.644	31.000	13.472					
	Huynh-Feldt	417.644	31.000	13.472					
	Lower-bound	417.644	31.000	13.472					
Condition	Sphericity Assumed	84.288	1	84.288	3.351	.077	.098	3.351	.426
	Greenhouse-Geisser	84.288	1.000	84.288	3.351	.077	.098	3.351	.426
	Huynh-Feldt	84.288	1.000	84.288	3.351	.077	.098	3.351	.426
	Lower-bound	84.288	1.000	84.288	3.351	.077	.098	3.351	.426
Condition * Group	Sphericity Assumed	.264	1	.264	.011	.919	.000	.011	.051
	Greenhouse-Geisser	.264	1.000	.264	.011	.919	.000	.011	.051
	Huynh-Feldt	.264	1.000	.264	.011	.919	.000	.011	.051
	Lower-bound	.264	1.000	.264	.011	.919	.000	.011	.051
Error(Condition)	Sphericity Assumed	779.797	31	25.155					
	Greenhouse-Geisser	779.797	31.000	25.155					
	Huynh-Feldt	779.797	31.000	25.155					
	Lower-bound	779.797	31.000	25.155					
Movement * Condition	Sphericity Assumed	64.044	1	64.044	2.550	.120	.076	2.550	.340
	Greenhouse-Geisser	64.044	1.000	64.044	2.550	.120	.076	2.550	.340

	Huynh-Feldt	64.044	1.000	64.044	2.550	.120	.076	2.550	.340
	Lower-bound	64.044	1.000	64.044	2.550	.120	.076	2.550	.340
Movement * Condition * Group	Sphericity Assumed	5.473	1	5.473	.218	.644	.007	.218	.074
	Greenhouse-Geisser	5.473	1.000	5.473	.218	.644	.007	.218	.074
	Huynh-Feldt	5.473	1.000	5.473	.218	.644	.007	.218	.074
	Lower-bound	5.473	1.000	5.473	.218	.644	.007	.218	.074
Error(Movement*Condition)	Sphericity Assumed	778.480	31	25.112					
	Greenhouse-Geisser	778.480	31.000	25.112					
	Huynh-Feldt	778.480	31.000	25.112					
	Lower-bound	778.480	31.000	25.112					

a. Computed using alpha = .05

Tests of Between-Subjects Effects

Measure:MEASURE_1
Transformed Variable:Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Intercept	175051.154	1	175051.154	1379.150	.000	.978	1379.150	1.000
Group	46.773	1	46.773	.369	.548	.012	.369	.091
Error	3934.731	31	126.927					

a. Computed using alpha = .05

2. Group

Estimates

Measure:MEASURE_1

Group	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1.000000000000	37.873	1.260	35.304	40.442
2.000000000000	36.655	1.562	33.469	39.842

Pairwise Comparisons

Measure:MEASURE_1

(I) Group	(J) Group	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1.000000000000	2.000000000000	1.218	2.007	.548	-2.875	5.311
2.000000000000	1.000000000000	-1.218	2.007	.548	-5.311	2.875

Based on estimated marginal means

a. Adjustment for multiple comparisons: Bonferroni.

3. Movement

Estimates

Measure:MEASURE_1

Movement	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1	33.218	1.024	31.130	35.306
2	41.311	1.086	39.096	43.526

Pairwise Comparisons

Measure:MEASURE_1

(I) Movement	(J) Movement	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1	2	-8.093*	.654	.000	-9.426	-6.759
2	1	8.093*	.654	.000	6.759	9.426

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

a. Adjustment for multiple comparisons: Bonferroni.

4. Condition

Estimates

Measure:MEASURE_1

Condition	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1	36.447	1.171	34.059	38.834
2	38.082	1.021	36.000	40.164

Pairwise Comparisons

Measure:MEASURE_1

(I) Condition	(J) Condition	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1	2	-1.635	.893	.077	-3.458	.187
2	1	1.635	.893	.077	-.187	3.458

Based on estimated marginal means

a. Adjustment for multiple comparisons: Bonferroni.

Initial Contact Hip Adduction:

Tests of Within-Subjects Effects

Measure:MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Movement	Sphericity Assumed	2463.891	1	2463.891	132.003	.000	.810	132.003	1.000
	Greenhouse-Geisser	2463.891	1.000	2463.891	132.003	.000	.810	132.003	1.000
	Huynh-Feldt	2463.891	1.000	2463.891	132.003	.000	.810	132.003	1.000
	Lower-bound	2463.891	1.000	2463.891	132.003	.000	.810	132.003	1.000
Movement * Group	Sphericity Assumed	10.299	1	10.299	.552	.463	.017	.552	.111
	Greenhouse-Geisser	10.299	1.000	10.299	.552	.463	.017	.552	.111
	Huynh-Feldt	10.299	1.000	10.299	.552	.463	.017	.552	.111
	Lower-bound	10.299	1.000	10.299	.552	.463	.017	.552	.111
Error(Movement)	Sphericity Assumed	578.628	31	18.665					
	Greenhouse-Geisser	578.628	31.000	18.665					
	Huynh-Feldt	578.628	31.000	18.665					
	Lower-bound	578.628	31.000	18.665					
Condition	Sphericity Assumed	9.617	1	9.617	.829	.370	.026	.829	.143
	Greenhouse-Geisser	9.617	1.000	9.617	.829	.370	.026	.829	.143
	Huynh-Feldt	9.617	1.000	9.617	.829	.370	.026	.829	.143
	Lower-bound	9.617	1.000	9.617	.829	.370	.026	.829	.143
Condition * Group	Sphericity Assumed	20.045	1	20.045	1.728	.198	.053	1.728	.247
	Greenhouse-Geisser	20.045	1.000	20.045	1.728	.198	.053	1.728	.247
	Huynh-Feldt	20.045	1.000	20.045	1.728	.198	.053	1.728	.247
	Lower-bound	20.045	1.000	20.045	1.728	.198	.053	1.728	.247
Error(Condition)	Sphericity Assumed	359.549	31	11.598					
	Greenhouse-Geisser	359.549	31.000	11.598					
	Huynh-Feldt	359.549	31.000	11.598					
	Lower-bound	359.549	31.000	11.598					
Movement * Condition	Sphericity Assumed	.016	1	.016	.001	.970	.000	.001	.050
	Greenhouse-Geisser	.016	1.000	.016	.001	.970	.000	.001	.050
	Huynh-Feldt	.016	1.000	.016	.001	.970	.000	.001	.050
	Lower-bound	.016	1.000	.016	.001	.970	.000	.001	.050
Movement * Condition * Group	Sphericity Assumed	1.498	1	1.498	.135	.716	.004	.135	.065
	Greenhouse-Geisser	1.498	1.000	1.498	.135	.716	.004	.135	.065
	Huynh-Feldt	1.498	1.000	1.498	.135	.716	.004	.135	.065

	Lower-bound	1.498	1.000	1.498	.135	.716	.004	.135	.065
Error(Movement*Condition)	Sphericity Assumed	344.965	31	11.128					
	Greenhouse-Geisser	344.965	31.000	11.128					
	Huynh-Feldt	344.965	31.000	11.128					
	Lower-bound	344.965	31.000	11.128					

a. Computed using alpha = .05

Tests of Between-Subjects Effects

Measure:MEASURE_1
Transformed Variable:Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Intercept	1770.991	1	1770.991	40.998	.000	.569	40.998	1.000
Group	.429	1	.429	.010	.921	.000	.010	.051
Error	1339.102	31	43.197					

a. Computed using alpha = .05

2. Group

Estimates

Measure:MEASURE_1

Group	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1.000000000000	-3.690	.735	-5.188	-2.191
2.000000000000	-3.807	.911	-5.665	-1.948

Pairwise Comparisons

Measure:MEASURE_1

(I) Group	(J) Group	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1.000000000000	2.000000000000	.117	1.171	.921	-2.271	2.504
2.000000000000	1.000000000000	-.117	1.171	.921	-2.504	2.271

Based on estimated marginal means

a. Adjustment for multiple comparisons: Bonferroni.

3. Movement

Estimates

Measure:MEASURE_1

Movement	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1	-8.169	.730	-9.659	-6.680
2	.673	.669	-.693	2.038

Pairwise Comparisons

Measure:MEASURE_1

(I) Movement	(J) Movement	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1	2	-8.842*	.770	.000	-10.412	-7.272
2	1	8.842*	.770	.000	7.272	10.412

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

a. Adjustment for multiple comparisons: Bonferroni.

4. Condition

Estimates

Measure:MEASURE_1

Condition	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1	-4.024	.616	-5.280	-2.769
2	-3.472	.700	-4.900	-2.044

Pairwise Comparisons

Measure:MEASURE_1

(I) Condition	(J) Condition	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1	2	-.552	.607	.370	-1.790	.685
2	1	.552	.607	.370	-.685	1.790

Based on estimated marginal means

a. Adjustment for multiple comparisons: Bonferroni.

Initial Contact Knee Flexion

Tests of Within-Subjects Effects

Measure:MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Movement	Sphericity Assumed	3362.464	1	3362.464	96.772	.000	.757	96.772	1.000
	Greenhouse-Geisser	3362.464	1.000	3362.464	96.772	.000	.757	96.772	1.000
	Huynh-Feldt	3362.464	1.000	3362.464	96.772	.000	.757	96.772	1.000
	Lower-bound	3362.464	1.000	3362.464	96.772	.000	.757	96.772	1.000
Movement * Group	Sphericity Assumed	1.623	1	1.623	.047	.830	.002	.047	.055
	Greenhouse-Geisser	1.623	1.000	1.623	.047	.830	.002	.047	.055
	Huynh-Feldt	1.623	1.000	1.623	.047	.830	.002	.047	.055
	Lower-bound	1.623	1.000	1.623	.047	.830	.002	.047	.055
Error(Movement)	Sphericity Assumed	1077.137	31	34.746					
	Greenhouse-Geisser	1077.137	31.000	34.746					
	Huynh-Feldt	1077.137	31.000	34.746					
	Lower-bound	1077.137	31.000	34.746					
Condition	Sphericity Assumed	2.599	1	2.599	.066	.800	.002	.066	.057
	Greenhouse-Geisser	2.599	1.000	2.599	.066	.800	.002	.066	.057
	Huynh-Feldt	2.599	1.000	2.599	.066	.800	.002	.066	.057
	Lower-bound	2.599	1.000	2.599	.066	.800	.002	.066	.057
Condition * Group	Sphericity Assumed	28.916	1	28.916	.730	.399	.023	.730	.132
	Greenhouse-Geisser	28.916	1.000	28.916	.730	.399	.023	.730	.132
	Huynh-Feldt	28.916	1.000	28.916	.730	.399	.023	.730	.132
	Lower-bound	28.916	1.000	28.916	.730	.399	.023	.730	.132
Error(Condition)	Sphericity Assumed	1227.553	31	39.598					
	Greenhouse-Geisser	1227.553	31.000	39.598					
	Huynh-Feldt	1227.553	31.000	39.598					
	Lower-bound	1227.553	31.000	39.598					
Movement * Condition	Sphericity Assumed	77.720	1	77.720	1.502	.230	.046	1.502	.221
	Greenhouse-Geisser	77.720	1.000	77.720	1.502	.230	.046	1.502	.221
	Huynh-Feldt	77.720	1.000	77.720	1.502	.230	.046	1.502	.221
	Lower-bound	77.720	1.000	77.720	1.502	.230	.046	1.502	.221
Movement * Condition * Group	Sphericity Assumed	2.044	1	2.044	.040	.844	.001	.040	.054
	Greenhouse-Geisser	2.044	1.000	2.044	.040	.844	.001	.040	.054
	Huynh-Feldt	2.044	1.000	2.044	.040	.844	.001	.040	.054

	Lower-bound	2.044	1.000	2.044	.040	.844	.001	.040	.054
Error(Movement*Condition)	Sphericity Assumed	1603.979	31	51.741					
	Greenhouse-Geisser	1603.979	31.000	51.741					
	Huynh-Feldt	1603.979	31.000	51.741					
	Lower-bound	1603.979	31.000	51.741					

a. Computed using alpha = .05

Tests of Between-Subjects Effects

Measure:MEASURE_1
Transformed Variable:Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Intercept	51338.234	1	51338.234	466.320	.000	.938	466.320	1.000
Group	187.908	1	187.908	1.707	.201	.052	1.707	.245
Error	3412.864	31	110.092					

a. Computed using alpha = .05

2. Group

Estimates

Measure:MEASURE_1

Group	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1.000000000000	-21.401	1.173	-23.794	-19.009
2.000000000000	-18.960	1.455	-21.927	-15.992

Pairwise Comparisons

Measure:MEASURE_1

(I) Group	(J) Group	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1.000000000000	2.000000000000	-2.442	1.869	.201	-6.254	1.370
2.000000000000	1.000000000000	2.442	1.869	.201	-1.370	6.254

Based on estimated marginal means

a. Adjustment for multiple comparisons: Bonferroni.

3. Movement

Estimates

Measure:MEASURE_1

Movement	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1	-15.016	1.115	-17.291	-12.741
2	-25.345	1.027	-27.439	-23.251

Pairwise Comparisons

Measure:MEASURE_1

(I) Movement	(J) Movement	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1	2	10.329*	1.050	.000	8.188	12.471
2	1	-10.329*	1.050	.000	-12.471	-8.188

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

a. Adjustment for multiple comparisons: Bonferroni.

4. Condition

Estimates

Measure:MEASURE_1

Condition	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1	-20.037	1.117	-22.316	-17.758
2	-20.324	1.061	-22.489	-18.160

Pairwise Comparisons

Measure:MEASURE_1

(I) Condition	(J) Condition	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1	2	.287	1.121	.800	-1.999	2.573
2	1	-.287	1.121	.800	-2.573	1.999

Based on estimated marginal means

a. Adjustment for multiple comparisons: Bonferroni.

Initial Contact Knee Abduction

Tests of Within-Subjects Effects

Measure:MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Movement	Sphericity Assumed	7.860	1	7.860	2.184	.150	.066	2.184	.299
	Greenhouse-Geisser	7.860	1.000	7.860	2.184	.150	.066	2.184	.299
	Huynh-Feldt	7.860	1.000	7.860	2.184	.150	.066	2.184	.299
	Lower-bound	7.860	1.000	7.860	2.184	.150	.066	2.184	.299
Movement * Group	Sphericity Assumed	1.655	1	1.655	.460	.503	.015	.460	.101
	Greenhouse-Geisser	1.655	1.000	1.655	.460	.503	.015	.460	.101
	Huynh-Feldt	1.655	1.000	1.655	.460	.503	.015	.460	.101
	Lower-bound	1.655	1.000	1.655	.460	.503	.015	.460	.101
Error(Movement)	Sphericity Assumed	111.553	31	3.598					
	Greenhouse-Geisser	111.553	31.000	3.598					
	Huynh-Feldt	111.553	31.000	3.598					
	Lower-bound	111.553	31.000	3.598					
Condition	Sphericity Assumed	.216	1	.216	.020	.889	.001	.020	.052
	Greenhouse-Geisser	.216	1.000	.216	.020	.889	.001	.020	.052
	Huynh-Feldt	.216	1.000	.216	.020	.889	.001	.020	.052
	Lower-bound	.216	1.000	.216	.020	.889	.001	.020	.052
Condition * Group	Sphericity Assumed	.243	1	.243	.022	.883	.001	.022	.052
	Greenhouse-Geisser	.243	1.000	.243	.022	.883	.001	.022	.052
	Huynh-Feldt	.243	1.000	.243	.022	.883	.001	.022	.052
	Lower-bound	.243	1.000	.243	.022	.883	.001	.022	.052
Error(Condition)	Sphericity Assumed	340.105	31	10.971					
	Greenhouse-Geisser	340.105	31.000	10.971					
	Huynh-Feldt	340.105	31.000	10.971					
	Lower-bound	340.105	31.000	10.971					
Movement * Condition	Sphericity Assumed	2.705	1	2.705	.869	.359	.027	.869	.147
	Greenhouse-Geisser	2.705	1.000	2.705	.869	.359	.027	.869	.147
	Huynh-Feldt	2.705	1.000	2.705	.869	.359	.027	.869	.147
	Lower-bound	2.705	1.000	2.705	.869	.359	.027	.869	.147
Movement * Condition * Group	Sphericity Assumed	.149	1	.149	.048	.828	.002	.048	.055
	Greenhouse-Geisser	.149	1.000	.149	.048	.828	.002	.048	.055

	Huynh-Feldt	.149	1.000	.149	.048	.828	.002	.048	.055
	Lower-bound	.149	1.000	.149	.048	.828	.002	.048	.055
Error(Movement*Condition)	Sphericity Assumed	96.524	31	3.114					
	Greenhouse-Geisser	96.524	31.000	3.114					
	Huynh-Feldt	96.524	31.000	3.114					
	Lower-bound	96.524	31.000	3.114					

a. Computed using alpha = .05

Tests of Between-Subjects Effects

Measure:MEASURE_1

Transformed Variable:Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Intercept	3473.429	1	3473.429	130.556	.000	.808	130.556	1.000
Group	2.773	1	2.773	.104	.749	.003	.104	.061
Error	824.754	31	26.605					

a. Computed using alpha = .05

2. Group

Estimates

Measure:MEASURE_1

Group	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1.000000000000	-5.101	.577	-6.277	-3.925
2.000000000000	-5.397	.715	-6.856	-3.939

Pairwise Comparisons

Measure:MEASURE_1

(I) Group	(J) Group	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1.000000000000	2.000000000000	.297	.919	.749	-1.577	2.171
2.000000000000	1.000000000000	-.297	.919	.749	-2.171	1.577

Based on estimated marginal means

a. Adjustment for multiple comparisons: Bonferroni.

3. Movement

Estimates

Measure:MEASURE_1

Movement	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1	-4.999	.459	-5.936	-4.063
2	-5.499	.518	-6.555	-4.443

Pairwise Comparisons

Measure:MEASURE_1

(I) Movement	(J) Movement	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1	2	.499	.338	.150	-.190	1.189
2	1	-.499	.338	.150	-1.189	.190

Based on estimated marginal means

a. Adjustment for multiple comparisons: Bonferroni.

4. Condition

Estimates

Measure:MEASURE_1

Condition	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1	-5.208	.551	-6.332	-4.083
2	-5.291	.540	-6.393	-4.188

Pairwise Comparisons

Measure:MEASURE_1

(I) Condition	(J) Condition	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1	2	.083	.590	.889	-1.121	1.286
2	1	-.083	.590	.889	-1.286	1.121

Based on estimated marginal means

a. Adjustment for multiple comparisons: Bonferroni.

Peak Stance Hip Flexion

Tests of Within-Subjects Effects

Measure:MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Movement	Sphericity Assumed	7180.715	1	7180.715	102.319	.000	.767	102.319	1.000
	Greenhouse-Geisser	7180.715	1.000	7180.715	102.319	.000	.767	102.319	1.000
	Huynh-Feldt	7180.715	1.000	7180.715	102.319	.000	.767	102.319	1.000
	Lower-bound	7180.715	1.000	7180.715	102.319	.000	.767	102.319	1.000
Movement * Group	Sphericity Assumed	.026	1	.026	.000	.985	.000	.000	.050
	Greenhouse-Geisser	.026	1.000	.026	.000	.985	.000	.000	.050
	Huynh-Feldt	.026	1.000	.026	.000	.985	.000	.000	.050
	Lower-bound	.026	1.000	.026	.000	.985	.000	.000	.050
Error(Movement)	Sphericity Assumed	2175.571	31	70.180					
	Greenhouse-Geisser	2175.571	31.000	70.180					
	Huynh-Feldt	2175.571	31.000	70.180					
	Lower-bound	2175.571	31.000	70.180					
Condition	Sphericity Assumed	45.418	1	45.418	1.576	.219	.048	1.576	.229
	Greenhouse-Geisser	45.418	1.000	45.418	1.576	.219	.048	1.576	.229
	Huynh-Feldt	45.418	1.000	45.418	1.576	.219	.048	1.576	.229
	Lower-bound	45.418	1.000	45.418	1.576	.219	.048	1.576	.229
Condition * Group	Sphericity Assumed	99.677	1	99.677	3.459	.072	.100	3.459	.437
	Greenhouse-Geisser	99.677	1.000	99.677	3.459	.072	.100	3.459	.437
	Huynh-Feldt	99.677	1.000	99.677	3.459	.072	.100	3.459	.437
	Lower-bound	99.677	1.000	99.677	3.459	.072	.100	3.459	.437
Error(Condition)	Sphericity Assumed	893.393	31	28.819					
	Greenhouse-Geisser	893.393	31.000	28.819					
	Huynh-Feldt	893.393	31.000	28.819					
	Lower-bound	893.393	31.000	28.819					
Movement * Condition	Sphericity Assumed	9.509	1	9.509	.516	.478	.016	.516	.107
	Greenhouse-Geisser	9.509	1.000	9.509	.516	.478	.016	.516	.107
	Huynh-Feldt	9.509	1.000	9.509	.516	.478	.016	.516	.107
	Lower-bound	9.509	1.000	9.509	.516	.478	.016	.516	.107
Movement * Condition * Group	Sphericity Assumed	.313	1	.313	.017	.897	.001	.017	.052
	Greenhouse-Geisser	.313	1.000	.313	.017	.897	.001	.017	.052
	Huynh-Feldt	.313	1.000	.313	.017	.897	.001	.017	.052

	Lower-bound	.313	1.000	.313	.017	.897	.001	.017	.052
Error(Movement*Condition)	Sphericity Assumed	571.795	31	18.445					
	Greenhouse-Geisser	571.795	31.000	18.445					
	Huynh-Feldt	571.795	31.000	18.445					
	Lower-bound	571.795	31.000	18.445					

a. Computed using alpha = .05

Tests of Between-Subjects Effects

Measure:MEASURE_1
Transformed Variable:Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Intercept	272208.263	1	272208.263	1890.583	.000	.984	1890.583	1.000
Group	385.337	1	385.337	2.676	.112	.079	2.676	.354
Error	4463.414	31	143.981					

a. Computed using alpha = .05

2. Group

Estimates

Measure:MEASURE_1

Group	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1.000000000000	48.217	1.342	45.481	50.953
2.000000000000	44.720	1.664	41.327	48.114

Pairwise Comparisons

Measure:MEASURE_1

(I) Group	(J) Group	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1.000000000000	2.000000000000	3.497	2.137	.112	-.863	7.856
2.000000000000	1.000000000000	-3.497	2.137	.112	-7.856	.863

Based on estimated marginal means

a. Adjustment for multiple comparisons: Bonferroni.

Univariate Tests

Measure:MEASURE_1

	Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Contrast	96.334	1	96.334	2.676	.112	.079	2.676	.354
Error	1115.853	31	35.995					

The F tests the effect of Group. This test is based on the linearly independent pairwise comparisons among the estimated marginal means.

a. Computed using alpha = .05

3. Movement

Estimates

Measure:MEASURE_1

Movement	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1	38.921	1.098	36.681	41.162
2	54.016	1.480	50.997	57.035

Pairwise Comparisons

Measure:MEASURE_1

(I) Movement	(J) Movement	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1	2	-15.095*	1.492	.000	-18.138	-12.051
2	1	15.095*	1.492	.000	12.051	18.138

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

a. Adjustment for multiple comparisons: Bonferroni.

Multivariate Tests

	Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[b]
Pillai's trace	.767	102.319[a]	1.000	31.000	.000	.767	102.319	1.000
Wilks' lambda	.233	102.319[a]	1.000	31.000	.000	.767	102.319	1.000
Hotelling's trace	3.301	102.319[a]	1.000	31.000	.000	.767	102.319	1.000
Roy's largest root	3.301	102.319[a]	1.000	31.000	.000	.767	102.319	1.000

Each F tests the multivariate effect of Movement. These tests are based on the linearly independent pairwise comparisons among the estimated marginal means.

a. Exact statistic

b. Computed using alpha = .05

4. Condition

Estimates

Measure:MEASURE_1

Condition	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1	45.869	1.279	43.260	48.477
2	47.069	1.052	44.924	49.214

Pairwise Comparisons

Measure:MEASURE_1

(I) Condition	(J) Condition	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1	2	-1.200	.956	.219	-3.151	.750
2	1	1.200	.956	.219	-.750	3.151

Based on estimated marginal means

a. Adjustment for multiple comparisons: Bonferroni.

Multivariate Tests

	Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[b]
Pillai's trace	.048	1.576[a]	1.000	31.000	.219	.048	1.576	.229
Wilks' lambda	.952	1.576[a]	1.000	31.000	.219	.048	1.576	.229
Hotelling's trace	.051	1.576[a]	1.000	31.000	.219	.048	1.576	.229
Roy's largest root	.051	1.576[a]	1.000	31.000	.219	.048	1.576	.229

Each F tests the multivariate effect of Condition. These tests are based on the linearly independent pairwise comparisons among the estimated marginal means.

a. Exact statistic

b. Computed using alpha = .05

Peak Stance Hip Adduction

Tests of Within-Subjects Effects

Measure:MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Movement	Sphericity Assumed	674.034	1	674.034	26.376	.000	.460	26.376	.999
	Greenhouse-Geisser	674.034	1.000	674.034	26.376	.000	.460	26.376	.999
	Huynh-Feldt	674.034	1.000	674.034	26.376	.000	.460	26.376	.999
	Lower-bound	674.034	1.000	674.034	26.376	.000	.460	26.376	.999
Movement * Group	Sphericity Assumed	3.003	1	3.003	.118	.734	.004	.118	.063
	Greenhouse-Geisser	3.003	1.000	3.003	.118	.734	.004	.118	.063
	Huynh-Feldt	3.003	1.000	3.003	.118	.734	.004	.118	.063
	Lower-bound	3.003	1.000	3.003	.118	.734	.004	.118	.063
Error(Movement)	Sphericity Assumed	792.197	31	25.555					
	Greenhouse-Geisser	792.197	31.000	25.555					
	Huynh-Feldt	792.197	31.000	25.555					
	Lower-bound	792.197	31.000	25.555					
Condition	Sphericity Assumed	9.106	1	9.106	.687	.413	.022	.687	.127
	Greenhouse-Geisser	9.106	1.000	9.106	.687	.413	.022	.687	.127
	Huynh-Feldt	9.106	1.000	9.106	.687	.413	.022	.687	.127
	Lower-bound	9.106	1.000	9.106	.687	.413	.022	.687	.127
Condition * Group	Sphericity Assumed	.413	1	.413	.031	.861	.001	.031	.053
	Greenhouse-Geisser	.413	1.000	.413	.031	.861	.001	.031	.053
	Huynh-Feldt	.413	1.000	.413	.031	.861	.001	.031	.053
	Lower-bound	.413	1.000	.413	.031	.861	.001	.031	.053
Error(Condition)	Sphericity Assumed	410.831	31	13.253					
	Greenhouse-Geisser	410.831	31.000	13.253					
	Huynh-Feldt	410.831	31.000	13.253					
	Lower-bound	410.831	31.000	13.253					
Movement * Condition	Sphericity Assumed	1.869	1	1.869	.356	.555	.011	.356	.089
	Greenhouse-Geisser	1.869	1.000	1.869	.356	.555	.011	.356	.089
	Huynh-Feldt	1.869	1.000	1.869	.356	.555	.011	.356	.089
	Lower-bound	1.869	1.000	1.869	.356	.555	.011	.356	.089
Movement * Condition * Group	Sphericity Assumed	1.575	1	1.575	.300	.588	.010	.300	.083
	Greenhouse-Geisser	1.575	1.000	1.575	.300	.588	.010	.300	.083
	Huynh-Feldt	1.575	1.000	1.575	.300	.588	.010	.300	.083

	Lower-bound	1.575	1.000	1.575	.300	.588	.010	.300	.083
Error(Movement*Condition)	Sphericity Assumed	162.906	31	5.255					
	Greenhouse-Geisser	162.906	31.000	5.255					
	Huynh-Feldt	162.906	31.000	5.255					
	Lower-bound	162.906	31.000	5.255					

a. Computed using alpha = .05

Tests of Between-Subjects Effects

Measure:MEASURE_1
Transformed Variable:Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Intercept	1530.090	1	1530.090	23.207	.000	.428	23.207	.997
Group	32.942	1	32.942	.500	.485	.016	.500	.105
Error	2043.910	31	65.933					

a. Computed using alpha = .05

2. Group

Estimates

Measure:MEASURE_1

Group	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1.000000000000	2.973	.908	1.121	4.824
2.000000000000	3.995	1.126	1.699	6.292

Pairwise Comparisons

Measure:MEASURE_1

(I) Group	(J) Group	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1.000000000000	2.000000000000	-1.022	1.446	.485	-3.972	1.928
2.000000000000	1.000000000000	1.022	1.446	.485	-1.928	3.972

Based on estimated marginal means

a. Adjustment for multiple comparisons: Bonferroni.

Univariate Tests

Measure:MEASURE_1

	Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Contrast	8.235	1	8.235	.500	.485	.016	.500	.105
Error	510.977	31	16.483					

The F tests the effect of Group. This test is based on the linearly independent pairwise comparisons among the estimated marginal means.

a. Computed using alpha = .05

3. Movement

Estimates

Measure:MEASURE_1

Movement	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1	1.172	.967	-.800	3.144
2	5.796	.719	4.330	7.262

Pairwise Comparisons

Measure:MEASURE_1

(I) Movement	(J) Movement	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1	2	-4.625*	.900	.000	-6.461	-2.788
2	1	4.625*	.900	.000	2.788	6.461

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

a. Adjustment for multiple comparisons: Bonferroni.

Multivariate Tests

	Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[b]
Pillai's trace	.460	26.376[a]	1.000	31.000	.000	.460	26.376	.999
Wilks' lambda	.540	26.376[a]	1.000	31.000	.000	.460	26.376	.999
Hotelling's trace	.851	26.376[a]	1.000	31.000	.000	.460	26.376	.999
Roy's largest root	.851	26.376[a]	1.000	31.000	.000	.460	26.376	.999

Each F tests the multivariate effect of Movement. These tests are based on the linearly independent pairwise comparisons among the estimated marginal means.

a. Exact statistic

b. Computed using alpha = .05

4. Condition

Estimates

Measure:MEASURE_1

Condition	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1	3.753	.831	2.057	5.448
2	3.215	.752	1.682	4.748

Pairwise Comparisons

Measure:MEASURE_1

(I) Condition	(J) Condition	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1	2	.538	.648	.413	-.785	1.860
2	1	-.538	.648	.413	-1.860	.785

Based on estimated marginal means

a. Adjustment for multiple comparisons: Bonferroni.

Multivariate Tests

	Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[b]
Pillai's trace	.022	.687[a]	1.000	31.000	.413	.022	.687	.127
Wilks' lambda	.978	.687[a]	1.000	31.000	.413	.022	.687	.127
Hotelling's trace	.022	.687[a]	1.000	31.000	.413	.022	.687	.127
Roy's largest root	.022	.687[a]	1.000	31.000	.413	.022	.687	.127

Each F tests the multivariate effect of Condition. These tests are based on the linearly independent pairwise comparisons among the estimated marginal means.

a. Exact statistic

b. Computed using alpha = .05

Peak Stance Knee Flexion

Tests of Within-Subjects Effects

Measure:MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Movement	Sphericity Assumed	13118.180	1	13118.180	142.123	.000	.821	142.123	1.000
	Greenhouse-Geisser	13118.180	1.000	13118.180	142.123	.000	.821	142.123	1.000
	Huynh-Feldt	13118.180	1.000	13118.180	142.123	.000	.821	142.123	1.000
	Lower-bound	13118.180	1.000	13118.180	142.123	.000	.821	142.123	1.000
Movement * Group	Sphericity Assumed	98.885	1	98.885	1.071	.309	.033	1.071	.171
	Greenhouse-Geisser	98.885	1.000	98.885	1.071	.309	.033	1.071	.171
	Huynh-Feldt	98.885	1.000	98.885	1.071	.309	.033	1.071	.171
	Lower-bound	98.885	1.000	98.885	1.071	.309	.033	1.071	.171
Error(Movement)	Sphericity Assumed	2861.347	31	92.302					
	Greenhouse-Geisser	2861.347	31.000	92.302					
	Huynh-Feldt	2861.347	31.000	92.302					
	Lower-bound	2861.347	31.000	92.302					
Condition	Sphericity Assumed	182.198	1	182.198	4.975	.033	.138	4.975	.580
	Greenhouse-Geisser	182.198	1.000	182.198	4.975	.033	.138	4.975	.580
	Huynh-Feldt	182.198	1.000	182.198	4.975	.033	.138	4.975	.580
	Lower-bound	182.198	1.000	182.198	4.975	.033	.138	4.975	.580
Condition * Group	Sphericity Assumed	81.170	1	81.170	2.216	.147	.067	2.216	.303
	Greenhouse-Geisser	81.170	1.000	81.170	2.216	.147	.067	2.216	.303
	Huynh-Feldt	81.170	1.000	81.170	2.216	.147	.067	2.216	.303
	Lower-bound	81.170	1.000	81.170	2.216	.147	.067	2.216	.303
Error(Condition)	Sphericity Assumed	1135.337	31	36.624					
	Greenhouse-Geisser	1135.337	31.000	36.624					
	Huynh-Feldt	1135.337	31.000	36.624					
	Lower-bound	1135.337	31.000	36.624					
Movement * Condition	Sphericity Assumed	80.287	1	80.287	3.979	.055	.114	3.979	.489
	Greenhouse-Geisser	80.287	1.000	80.287	3.979	.055	.114	3.979	.489
	Huynh-Feldt	80.287	1.000	80.287	3.979	.055	.114	3.979	.489
	Lower-bound	80.287	1.000	80.287	3.979	.055	.114	3.979	.489
Movement * Condition * Group	Sphericity Assumed	93.308	1	93.308	4.624	.039	.130	4.624	.549
	Greenhouse-Geisser	93.308	1.000	93.308	4.624	.039	.130	4.624	.549
	Huynh-Feldt	93.308	1.000	93.308	4.624	.039	.130	4.624	.549

	Lower-bound	93.308	1.000	93.308	4.624	.039	.130	4.624	.549
Error(Movement*Condition)	Sphericity Assumed	625.556	31	20.179					
	Greenhouse-Geisser	625.556	31.000	20.179					
	Huynh-Feldt	625.556	31.000	20.179					
	Lower-bound	625.556	31.000	20.179					

a. Computed using alpha = .05

Tests of Between-Subjects Effects

Measure:MEASURE_1
Transformed Variable:Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Intercept	570569.131	1	570569.131	2845.991	.000	.989	2845.991	1.000
Group	1941.112	1	1941.112	9.682	.004	.238	9.682	.854
Error	6214.932	31	200.482					

a. Computed using alpha = .05

2. Group

Estimates

Measure:MEASURE_1

Group	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1.000000000000	-71.201	1.583	-74.429	-67.972
2.000000000000	-63.353	1.964	-67.357	-59.348

Pairwise Comparisons

Measure:MEASURE_1

(I) Group	(J) Group	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1.000000000000	2.000000000000	-7.848*	2.522	.004	-12.992	-2.704
2.000000000000	1.000000000000	7.848*	2.522	.004	2.704	12.992

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

a. Adjustment for multiple comparisons: Bonferroni.

Univariate Tests

Measure:MEASURE_1

	Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Contrast	485.278	1	485.278	9.682	.004	.238	9.682	.854
Error	1553.733	31	50.120					

The F tests the effect of Group. This test is based on the linearly independent pairwise comparisons among the estimated marginal means.

a. Computed using alpha = .05

3. Movement

Estimates

Measure:MEASURE_1

Movement	Mean	Std. Error	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
1	-57.076	1.281	-59.688	-54.463
2	-77.478	1.733	-81.013	-73.942

Pairwise Comparisons

Measure:MEASURE_1

(I) Movement	(J) Movement	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a] Lower Bound	95% Confidence Interval for Difference[a] Upper Bound
1	2	20.402*	1.711	.000	16.912	23.893
2	1	-20.402*	1.711	.000	-23.893	-16.912

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

a. Adjustment for multiple comparisons: Bonferroni.

Multivariate Tests

	Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[b]
Pillai's trace	.821	142.123[a]	1.000	31.000	.000	.821	142.123	1.000
Wilks' lambda	.179	142.123[a]	1.000	31.000	.000	.821	142.123	1.000
Hotelling's trace	4.585	142.123[a]	1.000	31.000	.000	.821	142.123	1.000
Roy's largest root	4.585	142.123[a]	1.000	31.000	.000	.821	142.123	1.000

Each F tests the multivariate effect of Movement. These tests are based on the linearly independent pairwise comparisons among the estimated marginal means.

a. Exact statistic

b. Computed using alpha = .05

4. Condition

Estimates

Measure:MEASURE_1

Condition	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1	-68.479	1.309	-71.148	-65.809
2	-66.074	1.431	-68.994	-63.155

Pairwise Comparisons

Measure:MEASURE_1

(I) Condition	(J) Condition	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1	2	-2.404[*]	1.078	.033	-4.603	-.206
2	1	2.404[*]	1.078	.033	.206	4.603

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

a. Adjustment for multiple comparisons: Bonferroni.

Multivariate Tests

	Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[b]
Pillai's trace	.138	4.975[a]	1.000	31.000	.033	.138	4.975	.580
Wilks' lambda	.862	4.975[a]	1.000	31.000	.033	.138	4.975	.580
Hotelling's trace	.160	4.975[a]	1.000	31.000	.033	.138	4.975	.580
Roy's largest root	.160	4.975[a]	1.000	31.000	.033	.138	4.975	.580

Each F tests the multivariate effect of Condition. These tests are based on the linearly independent pairwise comparisons among the estimated marginal means.

a. Exact statistic

b. Computed using alpha = .05

Peak Stance Knee Flexion Post Hoc:

Training Group:

Tests of Within-Subjects Effects

Measure:MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Movement	Sphericity Assumed	9833.332	1	9833.332	136.640	.000	.878	136.640	1.000
	Greenhouse-Geisser	9833.332	1.000	9833.332	136.640	.000	.878	136.640	1.000
	Huynh-Feldt	9833.332	1.000	9833.332	136.640	.000	.878	136.640	1.000
	Lower-bound	9833.332	1.000	9833.332	136.640	.000	.878	136.640	1.000
Error(Movement)	Sphericity Assumed	1367.340	19	71.965					
	Greenhouse-Geisser	1367.340	19.000	71.965					
	Huynh-Feldt	1367.340	19.000	71.965					
	Lower-bound	1367.340	19.000	71.965					
Condition	Sphericity Assumed	12.786	1	12.786	.362	.555	.019	.362	.088
	Greenhouse-Geisser	12.786	1.000	12.786	.362	.555	.019	.362	.088
	Huynh-Feldt	12.786	1.000	12.786	.362	.555	.019	.362	.088
	Lower-bound	12.786	1.000	12.786	.362	.555	.019	.362	.088
Error(Condition)	Sphericity Assumed	671.143	19	35.323					
	Greenhouse-Geisser	671.143	19.000	35.323					
	Huynh-Feldt	671.143	19.000	35.323					
	Lower-bound	671.143	19.000	35.323					
Movement * Condition	Sphericity Assumed	.310	1	.310	.018	.894	.001	.018	.052
	Greenhouse-Geisser	.310	1.000	.310	.018	.894	.001	.018	.052
	Huynh-Feldt	.310	1.000	.310	.018	.894	.001	.018	.052
	Lower-bound	.310	1.000	.310	.018	.894	.001	.018	.052
Error(Movement*Condition)	Sphericity Assumed	324.398	19	17.074					
	Greenhouse-Geisser	324.398	19.000	17.074					
	Huynh-Feldt	324.398	19.000	17.074					
	Lower-bound	324.398	19.000	17.074					

a. Computed using alpha = .05

2. Movement

Estimates

Measure:MEASURE_1

Movement	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1	-60.114	1.536	-63.330	-56.898
2	-82.288	2.162	-86.812	-77.763

Pairwise Comparisons

Measure:MEASURE_1

(I) Movement	(J) Movement	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1	2	22.174*	1.897	.000	18.203	26.144
2	1	-22.174*	1.897	.000	-26.144	-18.203

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

a. Adjustment for multiple comparisons: Bonferroni.

Multivariate Tests

	Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[b]
Pillai's trace	.878	136.640[a]	1.000	19.000	.000	.878	136.640	1.000
Wilks' lambda	.122	136.640[a]	1.000	19.000	.000	.878	136.640	1.000
Hotelling's trace	7.192	136.640[a]	1.000	19.000	.000	.878	136.640	1.000
Roy's largest root	7.192	136.640[a]	1.000	19.000	.000	.878	136.640	1.000

Each F tests the multivariate effect of Movement. These tests are based on the linearly independent pairwise comparisons among the estimated marginal means.

a. Exact statistic

b. Computed using alpha = .05

3. Condition

Estimates

Measure:MEASURE_1

Condition	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1	-71.601	1.546	-74.837	-68.364
2	-70.801	1.930	-74.841	-66.761

Pairwise Comparisons

Measure:MEASURE_1

(I) Condition	(J) Condition	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1	2	-.800	1.329	.555	-3.581	1.982
2	1	.800	1.329	.555	-1.982	3.581

Based on estimated marginal means

a. Adjustment for multiple comparisons: Bonferroni.

Multivariate Tests

	Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[b]
Pillai's trace	.019	.362[a]	1.000	19.000	.555	.019	.362	.088
Wilks' lambda	.981	.362[a]	1.000	19.000	.555	.019	.362	.088
Hotelling's trace	.019	.362[a]	1.000	19.000	.555	.019	.362	.088
Roy's largest root	.019	.362[a]	1.000	19.000	.555	.019	.362	.088

Each F tests the multivariate effect of Condition. These tests are based on the linearly independent pairwise comparisons among the estimated marginal means.

a. Exact statistic

b. Computed using alpha = .05

Control Group:

Tests of Within-Subjects Effects

Measure:MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Movement	Sphericity Assumed	4512.413	1	4512.413	36.244	.000	.751	36.244	1.000
	Greenhouse-Geisser	4512.413	1.000	4512.413	36.244	.000	.751	36.244	1.000
	Huynh-Feldt	4512.413	1.000	4512.413	36.244	.000	.751	36.244	1.000
	Lower-bound	4512.413	1.000	4512.413	36.244	.000	.751	36.244	1.000
Error(Movement)	Sphericity Assumed	1494.007	12	124.501					
	Greenhouse-Geisser	1494.007	12.000	124.501					
	Huynh-Feldt	1494.007	12.000	124.501					
	Lower-bound	1494.007	12.000	124.501					
Condition	Sphericity Assumed	208.968	1	208.968	5.402	.038	.310	5.402	.570
	Greenhouse-Geisser	208.968	1.000	208.968	5.402	.038	.310	5.402	.570
	Huynh-Feldt	208.968	1.000	208.968	5.402	.038	.310	5.402	.570
	Lower-bound	208.968	1.000	208.968	5.402	.038	.310	5.402	.570
Error(Condition)	Sphericity Assumed	464.194	12	38.683					
	Greenhouse-Geisser	464.194	12.000	38.683					
	Huynh-Feldt	464.194	12.000	38.683					
	Lower-bound	464.194	12.000	38.683					
Movement * Condition	Sphericity Assumed	143.015	1	143.015	5.699	.034	.322	5.699	.593
	Greenhouse-Geisser	143.015	1.000	143.015	5.699	.034	.322	5.699	.593
	Huynh-Feldt	143.015	1.000	143.015	5.699	.034	.322	5.699	.593
	Lower-bound	143.015	1.000	143.015	5.699	.034	.322	5.699	.593
Error(Movement*Condition)	Sphericity Assumed	301.158	12	25.096					
	Greenhouse-Geisser	301.158	12.000	25.096					
	Huynh-Feldt	301.158	12.000	25.096					
	Lower-bound	301.158	12.000	25.096					

a. Computed using alpha = .05

2. Movement

Estimates

Measure:MEASURE_1

Movement	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1	-54.037	2.127	-58.671	-49.404
2	-72.668	2.727	-78.610	-66.727

Pairwise Comparisons

Measure:MEASURE_1

(I) Movement	(J) Movement	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1	2	18.631[*]	3.095	.000	11.888	25.374
2	1	-18.631[*]	3.095	.000	-25.374	-11.888

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

a. Adjustment for multiple comparisons: Bonferroni.

Multivariate Tests

	Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[b]
Pillai's trace	.751	36.244[a]	1.000	12.000	.000	.751	36.244	1.000
Wilks' lambda	.249	36.244[a]	1.000	12.000	.000	.751	36.244	1.000
Hotelling's trace	3.020	36.244[a]	1.000	12.000	.000	.751	36.244	1.000
Roy's largest root	3.020	36.244[a]	1.000	12.000	.000	.751	36.244	1.000

Each F tests the multivariate effect of Movement. These tests are based on the linearly independent pairwise comparisons among the estimated marginal means.

a. Exact statistic

b. Computed using alpha = .05

3. Condition

Estimates

Measure:MEASURE_1

Condition	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1	-65.357	2.214	-70.182	-60.533
2	-61.348	1.938	-65.570	-57.126

Pairwise Comparisons

Measure:MEASURE_1

(I) Condition	(J) Condition	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1	2	-4.009*	1.725	.038	-7.768	-.251
2	1	4.009*	1.725	.038	.251	7.768

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

a. Adjustment for multiple comparisons: Bonferroni.

Multivariate Tests

	Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[b]
Pillai's trace	.310	5.402[a]	1.000	12.000	.038	.310	5.402	.570
Wilks' lambda	.690	5.402[a]	1.000	12.000	.038	.310	5.402	.570
Hotelling's trace	.450	5.402[a]	1.000	12.000	.038	.310	5.402	.570
Roy's largest root	.450	5.402[a]	1.000	12.000	.038	.310	5.402	.570

Each F tests the multivariate effect of Condition. These tests are based on the linearly independent pairwise comparisons among the estimated marginal means.

a. Exact statistic

b. Computed using alpha = .05

Pre-Training Bilateral Lnadings

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Pre_KneeX_Vert	Equal variances assumed	1.858	.183	-1.622	31	.115	-6.29393	3.88062	-14.20850	1.62065
	Equal variances not assumed			-1.553	22.099	.135	-6.29393	4.05178	-14.69463	2.10678

Post-Training Bilateral Landings

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Post0_KneeX_Vert	Equal variances assumed	.937	.341	-3.373	31	.002	-12.94502	3.83780	-20.77226	-5.11777
	Equal variances not assumed			-3.493	28.632	.002	-12.94502	3.70607	-20.52900	-5.36103

Peak Stance Knee Abduction

Tests of Within-Subjects Effects

Measure:MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Movement	Sphericity Assumed	191.101	1	191.101	22.521	.000	.421	22.521	.996
	Greenhouse-Geisser	191.101	1.000	191.101	22.521	.000	.421	22.521	.996
	Huynh-Feldt	191.101	1.000	191.101	22.521	.000	.421	22.521	.996
	Lower-bound	191.101	1.000	191.101	22.521	.000	.421	22.521	.996
Movement * Group	Sphericity Assumed	7.376	1	7.376	.869	.358	.027	.869	.148
	Greenhouse-Geisser	7.376	1.000	7.376	.869	.358	.027	.869	.148
	Huynh-Feldt	7.376	1.000	7.376	.869	.358	.027	.869	.148
	Lower-bound	7.376	1.000	7.376	.869	.358	.027	.869	.148
Error(Movement)	Sphericity Assumed	263.048	31	8.485					
	Greenhouse-Geisser	263.048	31.000	8.485					
	Huynh-Feldt	263.048	31.000	8.485					
	Lower-bound	263.048	31.000	8.485					
Condition	Sphericity Assumed	.973	1	.973	.020	.890	.001	.020	.052
	Greenhouse-Geisser	.973	1.000	.973	.020	.890	.001	.020	.052
	Huynh-Feldt	.973	1.000	.973	.020	.890	.001	.020	.052
	Lower-bound	.973	1.000	.973	.020	.890	.001	.020	.052
Condition * Group	Sphericity Assumed	18.974	1	18.974	.382	.541	.012	.382	.092
	Greenhouse-Geisser	18.974	1.000	18.974	.382	.541	.012	.382	.092
	Huynh-Feldt	18.974	1.000	18.974	.382	.541	.012	.382	.092
	Lower-bound	18.974	1.000	18.974	.382	.541	.012	.382	.092
Error(Condition)	Sphericity Assumed	1540.375	31	49.690					
	Greenhouse-Geisser	1540.375	31.000	49.690					
	Huynh-Feldt	1540.375	31.000	49.690					
	Lower-bound	1540.375	31.000	49.690					
Movement * Condition	Sphericity Assumed	.388	1	.388	.098	.756	.003	.098	.061
	Greenhouse-Geisser	.388	1.000	.388	.098	.756	.003	.098	.061
	Huynh-Feldt	.388	1.000	.388	.098	.756	.003	.098	.061
	Lower-bound	.388	1.000	.388	.098	.756	.003	.098	.061
Movement * Condition * Group	Sphericity Assumed	.028	1	.028	.007	.934	.000	.007	.051
	Greenhouse-Geisser	.028	1.000	.028	.007	.934	.000	.007	.051
	Huynh-Feldt	.028	1.000	.028	.007	.934	.000	.007	.051

	Lower-bound	.028	1.000	.028	.007	.934	.000	.007	.051
Error(Movement*Condition)	Sphericity Assumed	122.728	31	3.959					
	Greenhouse-Geisser	122.728	31.000	3.959					
	Huynh-Feldt	122.728	31.000	3.959					
	Lower-bound	122.728	31.000	3.959					

a. Computed using alpha = .05

Tests of Between-Subjects Effects

Measure:MEASURE_1
Transformed Variable:Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Intercept	25765.888	1	25765.888	249.803	.000	.890	249.803	1.000
Group	.017	1	.017	.000	.990	.000	.000	.050
Error	3197.493	31	103.145					

a. Computed using alpha = .05

2. Group

Estimates

Measure:MEASURE_1

Group	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1.000000000000	-14.285	1.135	-16.601	-11.969
2.000000000000	-14.308	1.408	-17.180	-11.436

Pairwise Comparisons

Measure:MEASURE_1

(I) Group	(J) Group	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1.000000000000	2.000000000000	.023	1.809	.990	-3.667	3.713
2.000000000000	1.000000000000	-.023	1.809	.990	-3.713	3.667

Based on estimated marginal means

a. Adjustment for multiple comparisons: Bonferroni.

Univariate Tests

Measure:MEASURE_1

	Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Contrast	.004	1	.004	.000	.990	.000	.000	.050
Error	799.373	31	25.786					

The F tests the effect of Group. This test is based on the linearly independent pairwise comparisons among the estimated marginal means.

a. Computed using alpha = .05

3. Movement

Estimates

Measure:MEASURE_1

Movement	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1	-13.065	.929	-14.960	-11.171
2	-15.528	.953	-17.471	-13.584

Pairwise Comparisons

Measure:MEASURE_1

(I) Movement	(J) Movement	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1	2	2.462*	.519	.000	1.404	3.521
2	1	-2.462*	.519	.000	-3.521	-1.404

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

a. Adjustment for multiple comparisons: Bonferroni.

Multivariate Tests

	Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[b]
Pillai's trace	.421	22.521[a]	1.000	31.000	.000	.421	22.521	.996
Wilks' lambda	.579	22.521[a]	1.000	31.000	.000	.421	22.521	.996
Hotelling's trace	.726	22.521[a]	1.000	31.000	.000	.421	22.521	.996
Roy's largest root	.726	22.521[a]	1.000	31.000	.000	.421	22.521	.996

Each F tests the multivariate effect of Movement. These tests are based on the linearly independent pairwise comparisons among the estimated marginal means.

a. Exact statistic

b. Computed using alpha = .05

4. Condition

Estimates

Measure:MEASURE_1

Condition	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1	-14.209	1.175	-16.604	-11.813
2	-14.384	1.022	-16.469	-12.300

Pairwise Comparisons

Measure:MEASURE_1

(I) Condition	(J) Condition	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1	2	.176	1.256	.890	-2.385	2.737
2	1	-.176	1.256	.890	-2.737	2.385

Based on estimated marginal means

a. Adjustment for multiple comparisons: Bonferroni.

Multivariate Tests

	Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[b]
Pillai's trace	.001	.020[a]	1.000	31.000	.890	.001	.020	.052
Wilks' lambda	.999	.020[a]	1.000	31.000	.890	.001	.020	.052
Hotelling's trace	.001	.020[a]	1.000	31.000	.890	.001	.020	.052
Roy's largest root	.001	.020[a]	1.000	31.000	.890	.001	.020	.052

Each F tests the multivariate effect of Condition. These tests are based on the linearly independent pairwise comparisons among the estimated marginal means.

a. Exact statistic

b. Computed using alpha = .05

Table E.6. Mean Peak Stance (0% - 50%) Phase Hip and Knee Kinematic Data for Bilateral and Unilateral Landings at Both Pre- and Post-Training Time Points for Aim 3.

	Pre-Training								**Post-Training**							
	Bilateral				**Unilateral**				**Bilateral**				**Unilateral**			
	Hip		**Knee**		**Hip**		**Knee**		**Hip**		**Knee**		**Hip**		**Knee**	
Subj ID	**Flx**	**Add**	**Flx**	**Abd**	**Flx**	**Add**	**Flx**	**Abd**	**Flx**	**Add**	**Flx**	**Abd**	**Flx**	**Add**	**Flx**	**Abd**
1	64.07	-2.76	-104.94	-4.41	44.35	-8.66	-72.59	-5.51	56.93	1.07	-83.79	-5.13	34.68	-9.08	-63.37	-6.60
8	47.72	-0.10	-91.23	-4.90	33.69	3.11	-60.94	-3.66	43.82	8.11	-80.14	-8.75	36.37	11.96	-65.10	-6.62
16	53.78	5.49	-88.41	-3.70	43.95	11.55	-59.42	-0.91	46.42	-0.16	-77.04	-7.86	38.54	2.36	-59.70	-5.09
34	43.00	8.24	-80.35	-14.74	38.08	9.18	-58.09	-12.30	50.11	-2.33	-85.87	-6.66	29.03	-11.08	-60.96	-9.42
35	50.03	1.46	-76.31	-7.47	31.35	0.31	-61.57	-7.94	46.52	5.21	-70.36	-3.92	28.26	-1.60	-46.98	-2.77
36	48.93	-3.64	-82.47	-4.05	34.24	-7.31	-62.02	-3.81	46.15	5.74	-79.27	-10.20	38.05	-0.72	-62.07	-9.79
38	61.84	-6.42	-89.54	-2.76	52.11	-3.43	-69.75	-3.42	71.24	-8.46	-84.59	-3.60	53.69	-1.46	-64.86	-2.73
39	46.98	-8.28	-66.60	1.66	33.09	-1.06	-55.67	-0.32	50.14	-8.00	-63.26	-0.37	33.67	-10.32	-46.46	-2.21
40	42.99	-5.12	-77.19	-6.94	35.95	4.59	-65.34	-4.54	55.12	1.44	-85.20	-3.76	44.97	8.17	-72.92	-3.46
41	42.14	-5.98	-63.61	-6.05	21.71	-9.68	-51.18	-2.82	61.11	0.36	-83.06	-5.73	33.47	-10.28	-57.53	-4.96
43	50.76	-6.55	-84.23	-2.75	44.96	2.51	-74.58	-3.35	56.49	-5.37	-93.65	-2.71	45.38	7.13	-78.94	-4.10
49	55.82	-8.60	-89.74	1.39	38.89	-5.98	-61.94	-0.44	75.48	-7.12	-93.76	-3.93	54.81	8.66	-75.15	-4.00
50	47.87	0.01	-84.34	-6.33	36.92	-2.74	-65.47	-6.77	56.63	-3.75	-78.22	-3.72	48.31	-7.59	-61.14	-4.88
51	50.58	-10.05	-66.83	-4.23	27.45	-10.22	-40.18	-3.57	63.90	-2.95	-75.83	-2.81	32.35	-6.44	-47.75	-2.68
52	46.41	-10.48	-58.40	-9.30	37.10	-5.17	-48.85	-7.43	49.09	-8.42	-70.19	-4.84	36.67	-14.45	-58.31	-4.72
53	52.04	9.21	-84.10	-2.55	34.21	1.72	-66.81	-1.41	62.53	3.84	-88.83	1.05	25.14	-12.16	-68.22	-0.63
54	31.38	-8.82	-64.16	-6.50	32.10	-8.59	-60.62	-3.94	45.30	-9.05	-77.85	-8.89	33.78	-6.99	-68.09	-5.76
59	42.79	-6.05	-71.75	-2.30	30.96	-7.70	-58.55	-2.77	54.09	-8.44	-75.85	-0.88	39.07	-5.72	-58.01	-0.10
60	61.12	5.48	-91.95	-5.45	41.51	12.77	-76.54	-7.23	61.22	0.00	-101.55	-11.58	47.14	7.84	-80.08	-12.60
61	63.04	-5.97	-83.28	1.10	37.67	-13.67	-71.14	-1.85	64.04	-5.17	-82.18	-3.48	27.46	-11.44	-72.81	-3.56
62	72.55	-4.82	-88.31	-1.66	33.83	-6.15	-60.53	-0.99	72.79	-4.74	-97.78	5.31	28.24	-11.03	-57.51	2.88
63	66.12	-4.91	-82.09	-8.27	52.40	-0.13	-64.15	-6.80	86.36	-2.89	-123.30	-9.92	46.10	3.08	-58.12	-8.88

Table E.6. cont'd

	Pre-Training								**Post-Training**							
	Bilateral				**Unilateral**				**Bilateral**				**Unilateral**			
	Hip		**Knee**		**Hip**		**Knee**		**Hip**		**Knee**		**Hip**		**Knee**	
Subj ID	**Flx**	**Add**	**Flx**	**Abd**	**Flx**	**Add**	**Flx**	**Abd**	**Flx**	**Add**	**Flx**	**Abd**	**Flx**	**Add**	**Flx**	**Abd**
64	37.84	-7.30	-66.70	-4.01	33.29	-6.08	-58.67	-3.15	42.14	-10.71	-76.77	-12.08	25.76	-8.81	-57.85	-9.43
65	51.39	2.60	-76.73	2.90	31.53	1.37	-53.24	-1.28	62.86	-3.16	-82.31	-3.43	26.25	-14.10	-41.74	-3.42
67	38.12	3.71	-66.53	-2.43	29.46	-0.16	-61.43	-2.34	49.40	3.11	-80.63	-3.91	35.34	-2.77	-61.51	-2.43
68	53.23	6.35	-82.61	0.32	47.11	14.57	-72.41	-0.69	54.30	4.07	-81.77	1.89	53.83	7.64	-68.20	0.70
74	49.07	-5.90	-77.61	-8.88	36.49	8.39	-65.44	-7.12	50.81	-4.19	-71.93	-4.28	43.78	4.55	-54.43	-2.19
7	38.45	1.66	-68.65	-4.59	34.41	7.78	-66.30	-0.85	37.86	-2.23	-73.70	-8.90	33.84	3.73	-68.82	-5.22
12	66.13	19.11	-88.39	-0.53	29.73	13.04	-48.50	-2.09	60.84	10.36	-83.27	-7.38	27.49	7.71	-45.80	-3.46
14	36.92	4.89	-88.15	-8.62	35.48	5.89	-65.67	-2.28	35.51	10.89	-87.63	-6.60	28.60	9.29	-65.99	-2.52
15	34.11	-7.61	-70.23	1.56	29.08	8.47	-63.85	1.37	30.32	-7.13	-64.32	-2.00	25.03	0.56	-50.81	-0.81
45	66.26	-1.66	-91.32	-4.00	37.49	-8.20	-59.89	-5.72	68.48	-3.79	-93.49	-6.76	34.87	-11.87	-60.20	-8.58
46	46.00	-2.79	-65.57	-1.71	32.85	-3.45	-50.59	-1.81	52.65	-4.78	-73.00	-0.78	36.50	-0.93	-52.51	1.19
47	40.57	-5.62	-65.54	-8.02	33.73	-0.92	-48.13	-4.19	31.09	-3.65	-65.99	-12.01	26.31	7.07	-55.87	-8.20
55	42.02	2.32	-74.54	1.02	20.90	-5.54	-53.66	-1.90	43.43	-2.54	-76.47	0.85	27.68	-4.45	-55.51	0.21
71	38.77	-9.48	-55.15	4.68	24.97	-7.50	-43.69	-0.48	51.02	-6.70	-58.05	-0.64	33.02	-6.63	-49.36	-0.66
78	61.09	-15.47	-84.40	4.80	45.46	-2.41	-62.70	0.31	68.43	-7.64	-86.48	0.41	50.40	-3.37	-60.67	0.62
37	63.50	-8.84	-90.66	2.45	49.79	-2.80	-76.79	1.29	58.76	-6.76	-82.10	1.68	46.92	-5.28	-69.85	0.14
76	54.88	-7.11	-79.80	-3.22	38.88	1.58	-60.36	-3.08	55.16	-3.96	-74.72	-5.55	38.65	-2.07	-54.42	-3.21
80	56.60	-7.99	-90.74	-6.62	39.62	2.19	-72.95	-5.02	61.12	-13.06	-93.27	-7.81	48.61	2.14	-66.52	-5.56
81	70.41	-7.36	-83.96	-0.36	35.40	-10.74	-44.77	-1.20	60.22	-7.80	-76.67	-1.43	30.97	-11.51	-41.59	0.15
82	65.80	2.48	-83.29	-2.84	41.38	6.47	-63.05	-2.78	73.42	-0.47	-88.68	-1.04	46.29	10.21	-62.67	-0.32
83	67.67	-6.37	-80.26	-8.67	38.32	-18.19	-62.02	-8.11	67.68	-2.59	-77.29	-6.59	44.54	-9.42	-61.26	-6.44

Table E.7. Mean Peak Stance (0% - 50%) Phase Hip and Knee Kinetic Data for Bilateral and Unilateral Landings at Both Pre- and Post-Training Time Points for Aim 3.

	Pre-Training								**Post-Training**							
	Bilateral				**Unilateral**				**Bilateral**				**Unilateral**			
	Hip		**Knee**		**Hip**		**Knee**		**Hip**		**Knee**		**Hip**		**Knee**	
Subj ID	**Flx**	**Add**	**Flx**	**Abd**	**Flx**	**Add**	**Flx**	**Abd**	**Flx**	**Add**	**Flx**	**Abd**	**Flx**	**Add**	**Flx**	**Abd**
1	-1.20	-0.23	0.88	0.23	-1.56	-0.45	1.25	0.90	-0.85	-0.33	0.99	0.24	-1.08	-0.68	1.69	0.42
8	-0.75	0.05	1.07	0.57	-0.60	-0.41	1.42	0.60	-0.85	-0.28	1.34	0.56	-1.05	-0.77	1.45	0.52
16	-0.95	-0.26	1.04	0.29	-1.12	-0.83	1.29	0.22	-0.92	-0.27	1.13	0.18	-1.08	-0.83	1.14	0.17
34	-0.85	-0.26	1.10	0.45	-1.02	-0.70	1.42	0.47	-0.95	-0.10	1.06	0.38	-0.71	-0.13	1.61	0.62
35	-1.13	-0.22	1.22	0.39	-0.84	-0.68	1.50	0.67	-0.99	-0.15	1.27	0.50	-0.79	-0.63	1.76	0.64
36	-0.82	-0.46	1.28	0.45	-0.96	-0.55	1.57	0.34	-0.85	-0.57	1.24	0.61	-0.87	-0.39	1.50	0.70
38	-1.07	-0.03	1.23	0.18	-1.23	-0.32	1.42	0.26	-0.94	-0.08	1.26	0.32	-1.36	-0.39	1.62	0.27
39	-1.09	-0.10	1.20	0.33	-1.37	-0.79	1.56	0.42	-0.76	-0.12	1.38	0.24	-1.05	-0.55	1.87	0.49
40	-0.72	-0.15	1.34	0.66	-1.05	-0.84	1.52	0.35	-0.72	-0.09	1.30	0.47	-0.90	-0.69	1.38	0.35
41	-0.89	-0.25	1.19	0.52	-0.77	-0.75	1.63	0.42	-0.99	-0.09	1.06	0.43	-1.05	-0.56	1.70	0.55
43	-1.43	-0.35	1.21	0.41	-1.39	-0.65	1.37	0.57	-0.65	-0.13	1.06	0.35	-0.89	-0.75	1.34	0.37
49	-1.12	-0.34	0.84	0.21	-1.56	-0.75	1.36	0.48	-1.16	-0.56	0.85	0.47	-1.48	-0.69	1.38	0.41
50	-0.76	-0.32	1.31	0.41	-1.00	-0.72	1.63	0.38	-0.77	-0.20	1.61	0.18	-0.68	-0.73	1.74	0.30
51	-0.89	-0.27	0.80	0.39	-1.03	-0.57	1.10	0.54	-0.89	-0.24	0.92	0.26	-0.85	-0.37	1.56	0.46
52	-0.95	-0.20	0.95	0.66	-1.02	-0.56	1.20	0.59	-0.72	-0.38	1.28	0.65	-0.81	-0.73	1.54	0.60
53	-0.89	-0.21	1.32	0.30	-0.74	-0.76	1.54	0.19	-1.21	-0.17	1.13	0.18	-0.89	-0.76	1.51	0.17
54	-1.01	-0.40	1.54	0.47	-1.19	-0.60	1.48	0.23	-0.76	-0.25	1.47	0.56	-1.04	-0.62	1.66	0.21
59	-0.75	-0.07	0.99	0.32	-0.67	-0.61	1.32	0.17	-0.72	-0.14	0.95	0.29	-0.85	-0.57	1.43	0.16
60	-1.02	-0.23	1.48	0.46	-1.14	-0.78	2.31	0.68	-1.04	-0.26	1.34	0.40	-1.43	-0.72	1.80	0.56
61	-0.89	-0.21	0.88	0.29	-1.24	-0.36	1.59	0.57	-0.87	-0.22	0.63	0.25	-1.18	-0.71	1.26	0.43
62	-0.91	0.00	0.76	0.21	-0.77	-0.51	1.74	0.32	-0.88	-0.08	0.91	0.10	-0.99	-0.48	1.77	0.31
63	-0.80	-0.22	0.80	0.37	-0.79	-0.83	1.16	0.27	-1.17	-0.31	1.65	0.34	-0.80	-0.95	1.27	0.28

Table E.7. cont'd

	Pre-Training								Post-Training							
	Bilateral				**Unilateral**				**Bilateral**				**Unilateral**			
	Hip		**Knee**		**Hip**		**Knee**		**Hip**		**Knee**		**Hip**		**Knee**	
Subj ID	**Flx**	**Add**	**Flx**	**Abd**	**Flx**	**Add**	**Flx**	**Abd**	**Flx**	**Add**	**Flx**	**Abd**	**Flx**	**Add**	**Flx**	**Abd**
64	-0.58	-0.15	1.17	0.25	-0.69	-0.39	1.20	0.16	-0.66	-0.05	0.92	0.26	-0.67	-0.56	1.43	0.16
65	-0.73	-0.32	1.02	0.25	-0.77	-0.83	1.47	0.31	-0.68	-0.13	0.99	0.21	-0.77	-0.35	1.55	0.41
67	-1.00	-0.63	1.61	0.64	-1.01	-1.08	1.53	0.44	-0.79	-0.28	1.17	0.41	-0.99	-0.67	1.56	0.54
68	-0.89	-0.26	1.22	0.22	-0.99	-0.54	1.59	0.36	-0.80	-0.29	1.30	0.12	-1.18	-0.58	1.31	0.43
74	-0.66	-0.25	1.05	0.47	-0.82	-0.33	1.52	0.35	-1.01	-0.14	1.33	0.45	-0.97	-0.32	1.60	0.35
7	-0.98	-0.47	1.51	0.92	-1.01	-0.43	2.04	0.56	-1.20	-0.47	1.68	0.75	-0.99	-0.56	1.68	0.48
12	-1.14	-0.53	1.09	0.18	-0.94	-0.84	1.77	0.79	-1.01	-0.41	1.08	0.30	-0.71	-0.91	1.40	0.38
14	-0.88	-0.23	1.56	0.54	-0.94	-0.52	1.67	0.50	-0.90	-0.34	1.43	0.40	-0.90	-0.82	1.81	0.17
15	-1.05	-0.60	1.32	0.29	-1.50	-0.52	1.51	0.31	-1.07	-0.64	1.29	0.17	-1.36	-0.88	1.24	0.14
45	-0.99	-0.54	1.01	0.20	-1.29	-0.67	1.64	0.28	-0.94	-0.34	1.00	0.23	-1.03	-0.27	2.10	0.21
46	-0.75	-0.16	1.14	0.31	-0.81	-0.66	1.38	0.33	-0.76	-0.12	1.02	0.29	-0.88	-0.59	1.45	0.19
47	-0.71	-0.08	1.35	0.52	-0.86	-0.81	1.53	0.17	-0.75	-0.14	1.56	0.67	-1.06	-0.96	1.69	0.23
55	-1.13	-0.51	1.57	0.25	-1.16	-0.78	1.80	0.49	-0.76	-0.15	1.63	0.39	-0.79	-0.71	2.04	0.41
71	-0.95	-0.23	1.80	0.38	-1.15	-0.29	1.98	0.57	-1.59	-0.24	1.34	0.43	-1.77	-0.54	1.76	0.45
78	-1.41	-0.75	1.01	0.29	-1.16	-0.62	1.18	0.41	-1.09	-0.55	0.84	0.19	-1.09	-0.68	1.00	0.26
37	-0.52	-0.40	0.99	0.32	-0.67	-0.66	1.53	0.09	-0.69	-0.25	1.22	0.26	-0.73	-0.78	1.50	0.05
76	-0.79	-0.17	0.80	0.25	-0.97	-0.39	1.42	0.46	-0.79	-0.27	1.08	0.61	-1.12	-0.38	1.54	0.66
80	-0.90	-0.28	1.06	0.42	-1.23	-0.78	1.79	0.17	-0.83	-0.30	1.03	0.41	-1.36	-0.84	1.39	0.21
81	-0.95	-0.23	0.85	0.35	-0.74	-0.26	1.92	0.55	-0.79	-0.19	1.17	0.31	-0.82	-0.42	1.95	0.40
82	-1.09	-0.11	0.96	0.28	-0.93	-0.62	1.50	0.41	-1.15	-0.24	0.94	0.28	-1.29	-0.45	1.44	0.40
83	-1.22	-0.28	1.40	0.32	-0.99	-0.02	2.12	0.50	-1.27	-0.25	1.58	0.35	-1.05	-0.18	2.12	0.39

Table E.8. Mean (SD) for Peak Stance (0% - 50%) Hip and Knee Rotations

		NM		**CORE**		**PLYO**		**CON**	
		Single	**Double**	**Single**	**Double**	**Single**	**Double**	**Single**	**Double**
Hip Flx*# π	**Pre**	35.8 (8.5)	48.4 (6.6)	38.3 (7.1)	55.4 (8.6)	36.4 (7.8)	52.1 (11.0)	35.6 (5.8)	51.7 (14.4)
	Post	39.8 (9.5)	56.6 (12.5)	39.5 (7.4)	56.8 (9.2)	35.7 (10.5)	58.2 (12.2)	35.5 (7.3)	51.6 (13.0)
Hip Addμ	**Pre**	-3.3 (4.8)	-7.0 (2.4)	-3.8 (4.0)	-5.9 (5.5)	1.0 (8.3)	0.7 (5.9)	0.4 (9.9)	-1.3 (8.2)
	Post	-1.3 (8.8)	-4.7 (3.5)	-4.4 (3.8)	-2.8 (5.9)	-4.6 (7.9)	-2.2 (4.1)	0.3 (8.2)	-1.4 (7.6)
Knee Flx*μσ	**Pre**	-56.5 (10.9)	-72.7 (11.5)	-63.1 (6.2)	-82.4 (7.2)	-63.7 (7.0)	-80.0 (7.5)	-60.3 (9.4)	-81.4 (13.4)
	Post	-61.0 (11.5)	-78.9 (10.8)	-58.9 (7.0)	-80.3 (7.8)	-61.4 (9.5)	-86.7 (13.8)	-59.2 (9.1)	-78.6 (9.6)
Knee Abd	**Pre**	-3.2 (2.1)	-3.9 (3.7)	-3.1 (3.2)	-2.0 (4.2)	-4.1 (3.5)	-3.8 (4.9)	-2.7 (2.5)	-3.5 (4.0)
	Post	-3.6 (2.4)	-4.1 (3.2)	-3.4 (4.2)	-3.6 (4.3)	-4.1 (4.7)	-3.8 (5.3)	-3.8 (2.6)	-5.6 (3.2)

* significant difference between movement type

significant difference between testing time

μ significant interaction between testing time and training group

π significant interaction between testing time and movement type

σ significant interaction between movement type, testing time and training group

Table E.9. Mean (SD) for Peak Stance (0% - 50%) Phase Hip and Knee Moments

		NM		**CORE**		**PLYO**		**CON**	
		Single	**Double**	**Single**	**Double**	**Single**	**Double**	**Single**	**Double**
Hip Flx*	**Pre**	-1.10 (0.26)	-0.96 (0.21)	-0.94 (0.23)	-0.92 (0.29)	-0.93 (0.18)	-0.85 (0.15)	-1.07 (0.27)	-1.00 (0.13)
	Post	-1.06 (0.23)	-0.83 (0.15)	-0.93 (0.15)	-0.87 (0.14)	-0.93 (0.23)	-0.89 (0.17)	-1.11 (0.27)	-1.02 (0.24)
Hip Add*#μ	**Pre**	-0.69 (0.16)	-0.22 (0.14)	-0.60 (0.10)	-0.37 (0.24)	-0.66 (0.22)	-0.27 (0.16)	-0.51 (0.24)	-0.29 (0.17)
	Post	-0.66 (0.19)	-0.20 (0.15)	-0.53 (0.18)	-0.32 (0.17)	-0.59 (0.22)	-0.18 (0.08)	-0.65 (0.22)	-0.32 (0.12)
Knee Flx*	**Pre**	1.39 (0.17)	1.12 (0.19)	1.45 (0.16)	1.04 (0.16)	1.58 (0.29)	1.18 (0.28)	1.67 (0.29)	1.24 (0.30)
	Post	1.55 (0.16)	1.16 (0.21)	1.55 (0.33)	1.09 (0.16)	1.58 (0.22)	1.21 (0.31)	1.60 (0.28)	1.27 (0.23)
Knee Abd#π	**Pre**	0.41 (0.13)	0.43 (0.17)	0.35 (0.19)	0.32 (0.08)	0.38 (0.15)	0.35 (0.13)	0.49 (0.22)	0.40 (0.20)
	Post	0.38 (0.14)	0.42 (0.15)	0.39 (0.27)	0.38 (0.18)	0.38 (0.14)	0.28 (0.12)	0.33 (0.13)	0.38 (0.17)

* significant difference between movement type

significant interaction between testing time and training group

μ significant interaction between movement type and training group

π significant interaction between movement type, testing time and training group

Table E.10. P-value and observed power (1 – β) for main effect of training group (NM, CORE, PLYO and CON).

		p-value	1 - β
Hip Flexion	**Angle**	0.776	0.116
	Moment	0.081	0.559
Hip Adduction	**Angle**	0.299	0.312
	Moment	0.971	0.063
Knee Flexion	**Angle**	0.432	0.237
	Moment	0.211	0.382
Knee Abduction	**Angle**	0.929	0.075
	Moment	0.558	0.185

Table E.11. P-value and observed power (1 – β) for main effect of testing time (Pre vs. Post).

		p-value	1 - β
Hip Flexion	**Angle**	0.011	0.746
	Moment	0.582	0.084
Hip Adduction	**Angle**	0.737	0.063
	Moment	0.393	0.134
Knee Flexion	**Angle**	0.541	0.092
	Moment	0.155	0.293
Knee Abduction	**Angle**	0.168	0.278
	Moment	0.142	0.310

Table E.12. P-value and observed power (1 – β) for main effect of landing type (Bilateral vs Unilateral).

		p-value	1 - β
Hip Flexion	**Angle**	< 0.001	1.000
	Moment	0.002	0.893
Hip Adduction	**Angle**	0.275	0.191
	Moment	< 0.001	1.000
Knee Flexion	**Angle**	< 0.001	1.000
	Moment	< 0.001	1.000
Knee Abduction	**Angle**	0.299	0.177
	Moment	0.552	0.090

AIM 3 STATISTICAL OUTPUT

Peak Stance Hip Flexion Angle

Tests of Within-Subjects Effects

Measure:MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Condition	Sphericity Assumed	252.912	1	252.912	7.226	.011	.156	7.226	.746
	Greenhouse-Geisser	252.912	1.000	252.912	7.226	.011	.156	7.226	.746
	Huynh-Feldt	252.912	1.000	252.912	7.226	.011	.156	7.226	.746
	Lower-bound	252.912	1.000	252.912	7.226	.011	.156	7.226	.746
Condition * Group	Sphericity Assumed	227.200	3	75.733	2.164	.108	.143	6.491	.509
	Greenhouse-Geisser	227.200	3.000	75.733	2.164	.108	.143	6.491	.509
	Huynh-Feldt	227.200	3.000	75.733	2.164	.108	.143	6.491	.509
	Lower-bound	227.200	3.000	75.733	2.164	.108	.143	6.491	.509
Error(Condition)	Sphericity Assumed	1365.015	39	35.000					
	Greenhouse-Geisser	1365.015	39.000	35.000					
	Huynh-Feldt	1365.015	39.000	35.000					
	Lower-bound	1365.015	39.000	35.000					
Movement	Sphericity Assumed	11352.685	1	11352.685	122.782	.000	.759	122.782	1.000
	Greenhouse-Geisser	11352.685	1.000	11352.685	122.782	.000	.759	122.782	1.000
	Huynh-Feldt	11352.685	1.000	11352.685	122.782	.000	.759	122.782	1.000
	Lower-bound	11352.685	1.000	11352.685	122.782	.000	.759	122.782	1.000
Movement * Group	Sphericity Assumed	118.879	3	39.626	.429	.734	.032	1.286	.128
	Greenhouse-Geisser	118.879	3.000	39.626	.429	.734	.032	1.286	.128
	Huynh-Feldt	118.879	3.000	39.626	.429	.734	.032	1.286	.128
	Lower-bound	118.879	3.000	39.626	.429	.734	.032	1.286	.128
Error(Movement)	Sphericity Assumed	3606.029	39	92.462					
	Greenhouse-Geisser	3606.029	39.000	92.462					
	Huynh-Feldt	3606.029	39.000	92.462					
	Lower-bound	3606.029	39.000	92.462					
Condition * Movement	Sphericity Assumed	80.172	1	80.172	6.206	.017	.137	6.206	.681
	Greenhouse-Geisser	80.172	1.000	80.172	6.206	.017	.137	6.206	.681
	Huynh-Feldt	80.172	1.000	80.172	6.206	.017	.137	6.206	.681

	Lower-bound	80.172	1.000	80.172	6.206	.017	.137	6.206	.681
Condition * Movement * Group	Sphericity Assumed	93.953	3	31.318	2.424	.080	.157	7.273	.561
	Greenhouse-Geisser	93.953	3.000	31.318	2.424	.080	.157	7.273	.561
	Huynh-Feldt	93.953	3.000	31.318	2.424	.080	.157	7.273	.561
	Lower-bound	93.953	3.000	31.318	2.424	.080	.157	7.273	.561
Error(Condition*Movement)	Sphericity Assumed	503.810	39	12.918					
	Greenhouse-Geisser	503.810	39.000	12.918					
	Huynh-Feldt	503.810	39.000	12.918					
	Lower-bound	503.810	39.000	12.918					

a. Computed using alpha = .05

Tests of Between-Subjects Effects

Measure:MEASURE_1
Transformed Variable:Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Intercept	333347.167	1	333347.167	1273.312	.000	.970	1273.312	1.000
Group	289.501	3	96.500	.369	.776	.028	1.106	.116
Error	10210.015	39	261.795					

a. Computed using alpha = .05

2. Group

Estimates

Measure:MEASURE_1

Group	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1	45.152	2.558	39.977	50.326
2	47.480	3.058	41.295	53.665
3	45.605	2.244	41.067	50.144
4	43.587	2.244	39.048	48.125

Pairwise Comparisons

Measure:MEASURE_1

(I) Group	(J) Group	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1	2	-2.328	3.987	1.000	-13.410	8.753
	3	-.454	3.403	1.000	-9.912	9.005
	4	1.565	3.403	1.000	-7.894	11.023
2	1	2.328	3.987	1.000	-8.753	13.410
	3	1.875	3.793	1.000	-8.667	12.417
	4	3.893	3.793	1.000	-6.649	14.435
3	1	.454	3.403	1.000	-9.005	9.912
	2	-1.875	3.793	1.000	-12.417	8.667
	4	2.019	3.173	1.000	-6.802	10.839
4	1	-1.565	3.403	1.000	-11.023	7.894
	2	-3.893	3.793	1.000	-14.435	6.649
	3	-2.019	3.173	1.000	-10.839	6.802

Based on estimated marginal means

a. Adjustment for multiple comparisons: Bonferroni.

3. Condition

Estimates

Measure:MEASURE_1

Condition	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1	44.204	1.276	41.623	46.785
2	46.708	1.432	43.811	49.605

Pairwise Comparisons

Measure:MEASURE_1

(I) Condition	(J) Condition	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1	2	-2.504[*]	.932	.011	-4.388	-.620
2	1	2.504[*]	.932	.011	.620	4.388

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

a. Adjustment for multiple comparisons: Bonferroni.

4. Movement

Estimates

Measure:MEASURE_1

Movement	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1	53.845	1.736	50.333	57.356
2	37.067	1.174	34.693	39.442

Pairwise Comparisons

Measure:MEASURE_1

(I) Movement	(J) Movement	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1	2	16.777*	1.514	.000	13.715	19.840
2	1	-16.777*	1.514	.000	-19.840	-13.715

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

a. Adjustment for multiple comparisons: Bonferroni.

Peak Stance Hip Flexion Angle Post Hoc:

Tests of Within-Subjects Effects

Measure:MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Condition	Sphericity Assumed	252.007	1	252.007	6.648	.014	.137	6.648	.712
	Greenhouse-Geisser	252.007	1.000	252.007	6.648	.014	.137	6.648	.712
	Huynh-Feldt	252.007	1.000	252.007	6.648	.014	.137	6.648	.712
	Lower-bound	252.007	1.000	252.007	6.648	.014	.137	6.648	.712
Error(Condition)	Sphericity Assumed	1592.216	42	37.910					
	Greenhouse-Geisser	1592.216	42.000	37.910					
	Huynh-Feldt	1592.216	42.000	37.910					
	Lower-bound	1592.216	42.000	37.910					
Movement	Sphericity Assumed	12225.521	1	12225.521	137.848	.000	.766	137.848	1.000
	Greenhouse-Geisser	12225.521	1.000	12225.521	137.848	.000	.766	137.848	1.000
	Huynh-Feldt	12225.521	1.000	12225.521	137.848	.000	.766	137.848	1.000
	Lower-bound	12225.521	1.000	12225.521	137.848	.000	.766	137.848	1.000
Error(Movement)	Sphericity Assumed	3724.909	42	88.688					
	Greenhouse-Geisser	3724.909	42.000	88.688					
	Huynh-Feldt	3724.909	42.000	88.688					
	Lower-bound	3724.909	42.000	88.688					
Condition * Movement	Sphericity Assumed	101.587	1	101.587	7.138	.011	.145	7.138	.742
	Greenhouse-Geisser	101.587	1.000	101.587	7.138	.011	.145	7.138	.742
	Huynh-Feldt	101.587	1.000	101.587	7.138	.011	.145	7.138	.742
	Lower-bound	101.587	1.000	101.587	7.138	.011	.145	7.138	.742
Error(Condition*Movement)	Sphericity Assumed	597.763	42	14.232					
	Greenhouse-Geisser	597.763	42.000	14.232					
	Huynh-Feldt	597.763	42.000	14.232					
	Lower-bound	597.763	42.000	14.232					

a. Computed using alpha =

2. Condition

Estimates

Measure:MEASURE_1

Condition	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1	43.984	1.213	41.537	46.432
2	46.405	1.370	43.640	49.170

Pairwise Comparisons

Measure:MEASURE_1

(I) Condition	(J) Condition	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1	2	-2.421[*]	.939	.014	-4.316	-.526
2	1	2.421[*]	.939	.014	.526	4.316

Based on estimated marginal means

*. The mean difference is significant at the

a. Adjustment for multiple comparisons: Bonferroni.

3. Movement

Estimates

Measure:MEASURE_1

Movement	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1	53.626	1.643	50.309	56.942
2	36.764	1.112	34.519	39.009

Pairwise Comparisons

Measure:MEASURE_1

(I) Movement	(J) Movement	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1	2	16.862*	1.436	.000	13.963	19.760
2	1	-16.862*	1.436	.000	-19.760	-13.963

Based on estimated marginal means

*. The mean difference is significant at the

a. Adjustment for multiple comparisons: Bonferroni.

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	PreRtHipXVert - Post0RtHipXVert	-3.95790977	7.74776413	1.18152295	-6.34231962	-1.57349991	-3.350	42	.002
Pair 2	PreRtHipXAn - Post0RtHipXAn	-.88383372	6.65258050	1.01450902	-2.93119580	1.16352836	-.871	42	.389

Peak Stance Hip Adduction Angle:

Tests of Within-Subjects Effects

Measure:MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Condition	Sphericity Assumed	2.378	1	2.378	.115	.737	.003	.115	.063
	Greenhouse-Geisser	2.378	1.000	2.378	.115	.737	.003	.115	.063
	Huynh-Feldt	2.378	1.000	2.378	.115	.737	.003	.115	.063
	Lower-bound	2.378	1.000	2.378	.115	.737	.003	.115	.063
Condition * Group	Sphericity Assumed	279.168	3	93.056	4.493	.008	.257	13.478	.846
	Greenhouse-Geisser	279.168	3.000	93.056	4.493	.008	.257	13.478	.846
	Huynh-Feldt	279.168	3.000	93.056	4.493	.008	.257	13.478	.846
	Lower-bound	279.168	3.000	93.056	4.493	.008	.257	13.478	.846
Error(Condition)	Sphericity Assumed	807.772	39	20.712					
	Greenhouse-Geisser	807.772	39.000	20.712					
	Huynh-Feldt	807.772	39.000	20.712					
	Lower-bound	807.772	39.000	20.712					
Movement	Sphericity Assumed	51.052	1	51.052	1.225	.275	.030	1.225	.191
	Greenhouse-Geisser	51.052	1.000	51.052	1.225	.275	.030	1.225	.191
	Huynh-Feldt	51.052	1.000	51.052	1.225	.275	.030	1.225	.191
	Lower-bound	51.052	1.000	51.052	1.225	.275	.030	1.225	.191
Movement * Group	Sphericity Assumed	130.478	3	43.493	1.044	.384	.074	3.132	.261
	Greenhouse-Geisser	130.478	3.000	43.493	1.044	.384	.074	3.132	.261
	Huynh-Feldt	130.478	3.000	43.493	1.044	.384	.074	3.132	.261
	Lower-bound	130.478	3.000	43.493	1.044	.384	.074	3.132	.261
Error(Movement)	Sphericity Assumed	1624.971	39	41.666					
	Greenhouse-Geisser	1624.971	39.000	41.666					
	Huynh-Feldt	1624.971	39.000	41.666					
	Lower-bound	1624.971	39.000	41.666					
Condition * Movement	Sphericity Assumed	28.038	1	28.038	3.778	.059	.088	3.778	.474
	Greenhouse-Geisser	28.038	1.000	28.038	3.778	.059	.088	3.778	.474
	Huynh-Feldt	28.038	1.000	28.038	3.778	.059	.088	3.778	.474
	Lower-bound	28.038	1.000	28.038	3.778	.059	.088	3.778	.474
Condition * Movement * Group	Sphericity Assumed	25.769	3	8.590	1.157	.338	.082	3.472	.287
	Greenhouse-Geisser	25.769	3.000	8.590	1.157	.338	.082	3.472	.287
	Huynh-Feldt	25.769	3.000	8.590	1.157	.338	.082	3.472	.287
	Lower-bound	25.769	3.000	8.590	1.157	.338	.082	3.472	.287

Error(Condition*Movement)	Sphericity Assumed	289.463	39	7.422					
	Greenhouse-Geisser	289.463	39.000	7.422					
	Huynh-Feldt	289.463	39.000	7.422					
	Lower-bound	289.463	39.000	7.422					

a. Computed using alpha = .05

Tests of Between-Subjects Effects

Measure:MEASURE_1
Transformed Variable:Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Intercept	1021.254	1	1021.254	8.704	.005	.182	8.704	.820
Group	445.834	3	148.611	1.267	.299	.089	3.800	.312
Error	4576.105	39	117.336					

a. Computed using alpha = .05

2. Group

Estimates

Measure:MEASURE_1

Group	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1	-4.063	1.713	-7.527	-.598
2	-4.218	2.047	-8.359	-.077
3	-1.274	1.502	-4.312	1.765
4	-.510	1.502	-3.548	2.529

Pairwise Comparisons

Measure:MEASURE_1

(I) Group	(J) Group	Mean Difference (I-J)	Std. Error	Sig.^{a}	95% Confidence Interval for Difference^{a}	
					Lower Bound	Upper Bound
1	2	.155	2.669	1.000	-7.263	7.574
	3	-2.789	2.278	1.000	-9.121	3.544
	4	-3.553	2.278	.762	-9.885	2.779
2	1	-.155	2.669	1.000	-7.574	7.263
	3	-2.944	2.539	1.000	-10.002	4.113
	4	-3.708	2.539	.913	-10.766	3.349
3	1	2.789	2.278	1.000	-3.544	9.121
	2	2.944	2.539	1.000	-4.113	10.002
	4	-.764	2.124	1.000	-6.669	5.141
4	1	3.553	2.278	.762	-2.779	9.885
	2	3.708	2.539	.913	-3.349	10.766
	3	.764	2.124	1.000	-5.141	6.669

Based on estimated marginal means

a. Adjustment for multiple comparisons: Bonferroni.

3. Condition

Estimates

Measure:MEASURE_1

Condition	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1	-2.395	.959	-4.335	-.454
2	-2.637	.889	-4.436	-.838

Pairwise Comparisons

Measure:MEASURE_1

(I) Condition	(J) Condition	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1	2	.243	.717	.737	-1.207	1.692
2	1	-.243	.717	.737	-1.692	1.207

Based on estimated marginal means

a. Adjustment for multiple comparisons: Bonferroni.

4. Movement

Estimates

Measure:MEASURE_1

Movement	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1	-3.079	.858	-4.814	-1.343
2	-1.953	1.111	-4.201	.294

Pairwise Comparisons

Measure:MEASURE_1

(I) Movement	(J) Movement	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1	2	-1.125	1.016	.275	-3.181	.931
2	1	1.125	1.016	.275	-.931	3.181

Based on estimated marginal means

a. Adjustment for multiple comparisons: Bonferroni.

Peak Stance Hip Adduction Angle Post Hoc:

Group = 1

Tests of Within-Subjects Effects[b]

Measure:MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Condition	Sphericity Assumed	46.045	1	46.045	2.783	.130	.236	2.783	.320
	Greenhouse-Geisser	46.045	1.000	46.045	2.783	.130	.236	2.783	.320
	Huynh-Feldt	46.045	1.000	46.045	2.783	.130	.236	2.783	.320
	Lower-bound	46.045	1.000	46.045	2.783	.130	.236	2.783	.320
Error(Condition)	Sphericity Assumed	148.909	9	16.545					
	Greenhouse-Geisser	148.909	9.000	16.545					
	Huynh-Feldt	148.909	9.000	16.545					
	Lower-bound	148.909	9.000	16.545					
Movement	Sphericity Assumed	126.728	1	126.728	3.939	.078	.304	3.939	.426
	Greenhouse-Geisser	126.728	1.000	126.728	3.939	.078	.304	3.939	.426
	Huynh-Feldt	126.728	1.000	126.728	3.939	.078	.304	3.939	.426
	Lower-bound	126.728	1.000	126.728	3.939	.078	.304	3.939	.426
Error(Movement)	Sphericity Assumed	289.562	9	32.174					
	Greenhouse-Geisser	289.562	9.000	32.174					
	Huynh-Feldt	289.562	9.000	32.174					
	Lower-bound	289.562	9.000	32.174					
Condition * Movement	Sphericity Assumed	.225	1	.225	.015	.906	.002	.015	.051
	Greenhouse-Geisser	.225	1.000	.225	.015	.906	.002	.015	.051
	Huynh-Feldt	.225	1.000	.225	.015	.906	.002	.015	.051
	Lower-bound	.225	1.000	.225	.015	.906	.002	.015	.051
Error(Condition*Movement)	Sphericity Assumed	136.143	9	15.127					
	Greenhouse-Geisser	136.143	9.000	15.127					
	Huynh-Feldt	136.143	9.000	15.127					
	Lower-bound	136.143	9.000	15.127					

a. Computed using alpha =

Tests of Within-Subjects Effects[b]

Measure:MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Condition	Sphericity Assumed	46.045	1	46.045	2.783	.130	.236	2.783	.320
	Greenhouse-Geisser	46.045	1.000	46.045	2.783	.130	.236	2.783	.320
	Huynh-Feldt	46.045	1.000	46.045	2.783	.130	.236	2.783	.320
	Lower-bound	46.045	1.000	46.045	2.783	.130	.236	2.783	.320
Error(Condition)	Sphericity Assumed	148.909	9	16.545					
	Greenhouse-Geisser	148.909	9.000	16.545					
	Huynh-Feldt	148.909	9.000	16.545					
	Lower-bound	148.909	9.000	16.545					
Movement	Sphericity Assumed	126.728	1	126.728	3.939	.078	.304	3.939	.426
	Greenhouse-Geisser	126.728	1.000	126.728	3.939	.078	.304	3.939	.426
	Huynh-Feldt	126.728	1.000	126.728	3.939	.078	.304	3.939	.426
	Lower-bound	126.728	1.000	126.728	3.939	.078	.304	3.939	.426
Error(Movement)	Sphericity Assumed	289.562	9	32.174					
	Greenhouse-Geisser	289.562	9.000	32.174					
	Huynh-Feldt	289.562	9.000	32.174					
	Lower-bound	289.562	9.000	32.174					
Condition * Movement	Sphericity Assumed	.225	1	.225	.015	.906	.002	.015	.051
	Greenhouse-Geisser	.225	1.000	.225	.015	.906	.002	.015	.051
	Huynh-Feldt	.225	1.000	.225	.015	.906	.002	.015	.051
	Lower-bound	.225	1.000	.225	.015	.906	.002	.015	.051
Error(Condition*Movement)	Sphericity Assumed	136.143	9	15.127					
	Greenhouse-Geisser	136.143	9.000	15.127					
	Huynh-Feldt	136.143	9.000	15.127					
	Lower-bound	136.143	9.000	15.127					

a. Computed using alpha =

b. Group = 1

2. Condition

Estimates[a]

Measure:MEASURE_1

Condition	Mean	Std. Error	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
1	-5.135	.974	-7.339	-2.932
2	-2.990	1.606	-6.622	.642

a. Group = 1

Pairwise Comparisons[b]

Measure:MEASURE_1

(I) Condition	(J) Condition	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a] Lower Bound	95% Confidence Interval for Difference[a] Upper Bound
1	2	-2.146	1.286	.130	-5.056	.764
2	1	2.146	1.286	.130	-.764	5.056

Based on estimated marginal means

a. Adjustment for multiple comparisons: Bonferroni.

b. Group = 1

3. Movement

Estimates[a]

Measure:MEASURE_1

Movement	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1	-5.842	.790	-7.630	-4.054
2	-2.283	1.919	-6.624	2.059

a. Group = 1

Pairwise Comparisons[b]

Measure:MEASURE_1

(I) Movement	(J) Movement	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1	2	-3.560	1.794	.078	-7.618	.498
2	1	3.560	1.794	.078	-.498	7.618

Based on estimated marginal means

a. Adjustment for multiple comparisons: Bonferroni.

b. Group = 1

Group = 2

Tests of Within-Subjects Effects[b]

Measure:MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Condition	Sphericity Assumed	11.043	1	11.043	.896	.380	.130	.896	.127
	Greenhouse-Geisser	11.043	1.000	11.043	.896	.380	.130	.896	.127
	Huynh-Feldt	11.043	1.000	11.043	.896	.380	.130	.896	.127
	Lower-bound	11.043	1.000	11.043	.896	.380	.130	.896	.127
Error(Condition)	Sphericity Assumed	73.949	6	12.325					
	Greenhouse-Geisser	73.949	6.000	12.325					
	Huynh-Feldt	73.949	6.000	12.325					
	Lower-bound	73.949	6.000	12.325					
Movement	Sphericity Assumed	.510	1	.510	.014	.908	.002	.014	.051
	Greenhouse-Geisser	.510	1.000	.510	.014	.908	.002	.014	.051
	Huynh-Feldt	.510	1.000	.510	.014	.908	.002	.014	.051
	Lower-bound	.510	1.000	.510	.014	.908	.002	.014	.051
Error(Movement)	Sphericity Assumed	211.950	6	35.325					
	Greenhouse-Geisser	211.950	6.000	35.325					
	Huynh-Feldt	211.950	6.000	35.325					
	Lower-bound	211.950	6.000	35.325					
Condition * Movement	Sphericity Assumed	23.709	1	23.709	5.134	.064	.461	5.134	.477
	Greenhouse-Geisser	23.709	1.000	23.709	5.134	.064	.461	5.134	.477
	Huynh-Feldt	23.709	1.000	23.709	5.134	.064	.461	5.134	.477
	Lower-bound	23.709	1.000	23.709	5.134	.064	.461	5.134	.477
Error(Condition*Movement)	Sphericity Assumed	27.711	6	4.618					
	Greenhouse-Geisser	27.711	6.000	4.618					
	Huynh-Feldt	27.711	6.000	4.618					
	Lower-bound	27.711	6.000	4.618					

a. Computed using alpha =

b. Group = 2

2. Condition

Estimates[a]

Measure:MEASURE_1

Condition	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1	-4.846	1.189	-7.755	-1.937
2	-3.590	1.591	-7.484	.304

a. Group = 2

Pairwise Comparisons[b]

Measure:MEASURE_1

(I) Condition	(J) Condition	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1	2	-1.256	1.327	.380	-4.503	1.991
2	1	1.256	1.327	.380	-1.991	4.503

Based on estimated marginal means

a. Adjustment for multiple comparisons: Bonferroni.

b. Group = 2

3. Movement

Estimates[a]

Measure:MEASURE_1

Movement	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1	-4.353	1.979	-9.195	.489
2	-4.083	1.293	-7.248	-.918

a. Group = 2

Pairwise Comparisons[b]

Measure:MEASURE_1

(I) Movement	(J) Movement	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1	2	-.270	2.246	.908	-5.767	5.227
2	1	.270	2.246	.908	-5.227	5.767

Based on estimated marginal means

a. Adjustment for multiple comparisons: Bonferroni.

b. Group = 2

Group = 3

Tests of Within-Subjects Effects[b]

Measure:MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Condition	Sphericity Assumed	238.429	1	238.429	9.446	.010	.440	9.446	.805
	Greenhouse-Geisser	238.429	1.000	238.429	9.446	.010	.440	9.446	.805
	Huynh-Feldt	238.429	1.000	238.429	9.446	.010	.440	9.446	.805
	Lower-bound	238.429	1.000	238.429	9.446	.010	.440	9.446	.805
Error(Condition)	Sphericity Assumed	302.883	12	25.240					
	Greenhouse-Geisser	302.883	12.000	25.240					
	Huynh-Feldt	302.883	12.000	25.240					
	Lower-bound	302.883	12.000	25.240					
Movement	Sphericity Assumed	14.362	1	14.362	.311	.587	.025	.311	.081
	Greenhouse-Geisser	14.362	1.000	14.362	.311	.587	.025	.311	.081
	Huynh-Feldt	14.362	1.000	14.362	.311	.587	.025	.311	.081
	Lower-bound	14.362	1.000	14.362	.311	.587	.025	.311	.081
Error(Movement)	Sphericity Assumed	553.300	12	46.108					
	Greenhouse-Geisser	553.300	12.000	46.108					
	Huynh-Feldt	553.300	12.000	46.108					
	Lower-bound	553.300	12.000	46.108					
Condition * Movement	Sphericity Assumed	25.409	1	25.409	4.345	.059	.266	4.345	.483
	Greenhouse-Geisser	25.409	1.000	25.409	4.345	.059	.266	4.345	.483
	Huynh-Feldt	25.409	1.000	25.409	4.345	.059	.266	4.345	.483
	Lower-bound	25.409	1.000	25.409	4.345	.059	.266	4.345	.483
Error(Condition*Movement)	Sphericity Assumed	70.183	12	5.849					
	Greenhouse-Geisser	70.183	12.000	5.849					
	Huynh-Feldt	70.183	12.000	5.849					
	Lower-bound	70.183	12.000	5.849					

a. Computed using alpha =

b. Group = 3

2. Condition

Estimates[a]

Measure:MEASURE_1

Condition	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1	.867	1.753	-2.952	4.687
2	-3.415	1.400	-6.465	-.365

a. Group = 3

Pairwise Comparisons[b]

Measure:MEASURE_1

(I) Condition	(J) Condition	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1	2	4.283*	1.393	.010	1.247	7.319
2	1	-4.283*	1.393	.010	-7.319	-1.247

Based on estimated marginal means

*. The mean difference is significant at the

a. Adjustment for multiple comparisons: Bonferroni.

b. Group = 3

3. Movement

Estimates[a]

Measure:MEASURE_1

Movement	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1	-.748	1.315	-3.612	2.116
2	-1.799	2.027	-6.215	2.616

a. Group = 3

Pairwise Comparisons[b]

Measure:MEASURE_1

(I) Movement	(J) Movement	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1	2	1.051	1.883	.587	-3.052	5.154
2	1	-1.051	1.883	.587	-5.154	3.052

Based on estimated marginal means

a. Adjustment for multiple comparisons: Bonferroni.

b. Group = 3

Group = 4

Tests of Within-Subjects Effects[b]

Measure:MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Condition	Sphericity Assumed	.107	1	.107	.005	.947	.000	.005	.050
	Greenhouse-Geisser	.107	1.000	.107	.005	.947	.000	.005	.050
	Huynh-Feldt	.107	1.000	.107	.005	.947	.000	.005	.050
	Lower-bound	.107	1.000	.107	.005	.947	.000	.005	.050
Error(Condition)	Sphericity Assumed	282.032	12	23.503					
	Greenhouse-Geisser	282.032	12.000	23.503					
	Huynh-Feldt	282.032	12.000	23.503					
	Lower-bound	282.032	12.000	23.503					
Movement	Sphericity Assumed	38.525	1	38.525	.811	.386	.063	.811	.132
	Greenhouse-Geisser	38.525	1.000	38.525	.811	.386	.063	.811	.132
	Huynh-Feldt	38.525	1.000	38.525	.811	.386	.063	.811	.132
	Lower-bound	38.525	1.000	38.525	.811	.386	.063	.811	.132
Error(Movement)	Sphericity Assumed	570.159	12	47.513					
	Greenhouse-Geisser	570.159	12.000	47.513					
	Huynh-Feldt	570.159	12.000	47.513					
	Lower-bound	570.159	12.000	47.513					
Condition * Movement	Sphericity Assumed	.037	1	.037	.008	.930	.001	.008	.051
	Greenhouse-Geisser	.037	1.000	.037	.008	.930	.001	.008	.051
	Huynh-Feldt	.037	1.000	.037	.008	.930	.001	.008	.051
	Lower-bound	.037	1.000	.037	.008	.930	.001	.008	.051
Error(Condition*Movement)	Sphericity Assumed	55.427	12	4.619					
	Greenhouse-Geisser	55.427	12.000	4.619					
	Huynh-Feldt	55.427	12.000	4.619					
	Lower-bound	55.427	12.000	4.619					

a. Computed using alpha =
b. Group = 4

2. Condition

Estimates[a]

Measure:MEASURE_1

Condition	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1	-.464	2.298	-5.470	4.542
2	-.555	1.962	-4.829	3.719

a. Group = 4

Pairwise Comparisons[b]

Measure:MEASURE_1

(I) Condition	(J) Condition	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1	2	.091	1.345	.947	-2.839	3.020
2	1	-.091	1.345	.947	-3.020	2.839

Based on estimated marginal means

a. Adjustment for multiple comparisons: Bonferroni.

b. Group = 4

3. Movement

Estimates[a]

Measure:MEASURE_1

Movement	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1	-1.370	2.069	-5.878	3.138
2	.351	2.402	-4.882	5.584

a. Group = 4

Pairwise Comparisons[b]

Measure:MEASURE_1

(I) Movement	(J) Movement	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1	2	-1.721	1.912	.386	-5.887	2.444
2	1	1.721	1.912	.386	-2.444	5.887

Based on estimated marginal means

a. Adjustment for multiple comparisons: Bonferroni.

b. Group = 4

Peak Stance Knee Flexion Angle:

Tests of Within-Subjects Effects

Measure:MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Condition	Sphericity Assumed	14.726	1	14.726	.380	.541	.010	.380	.092
	Greenhouse-Geisser	14.726	1.000	14.726	.380	.541	.010	.380	.092
	Huynh-Feldt	14.726	1.000	14.726	.380	.541	.010	.380	.092
	Lower-bound	14.726	1.000	14.726	.380	.541	.010	.380	.092
Condition * Group	Sphericity Assumed	436.494	3	145.498	3.751	.018	.224	11.252	.769
	Greenhouse-Geisser	436.494	3.000	145.498	3.751	.018	.224	11.252	.769
	Huynh-Feldt	436.494	3.000	145.498	3.751	.018	.224	11.252	.769
	Lower-bound	436.494	3.000	145.498	3.751	.018	.224	11.252	.769
Error(Condition)	Sphericity Assumed	1512.884	39	38.792					
	Greenhouse-Geisser	1512.884	39.000	38.792					
	Huynh-Feldt	1512.884	39.000	38.792					
	Lower-bound	1512.884	39.000	38.792					
Movement	Sphericity Assumed	15473.545	1	15473.545	202.700	.000	.839	202.700	1.000
	Greenhouse-Geisser	15473.545	1.000	15473.545	202.700	.000	.839	202.700	1.000
	Huynh-Feldt	15473.545	1.000	15473.545	202.700	.000	.839	202.700	1.000
	Lower-bound	15473.545	1.000	15473.545	202.700	.000	.839	202.700	1.000
Movement * Group	Sphericity Assumed	97.402	3	32.467	.425	.736	.032	1.276	.127
	Greenhouse-Geisser	97.402	3.000	32.467	.425	.736	.032	1.276	.127
	Huynh-Feldt	97.402	3.000	32.467	.425	.736	.032	1.276	.127
	Lower-bound	97.402	3.000	32.467	.425	.736	.032	1.276	.127
Error(Movement)	Sphericity Assumed	2977.149	39	76.337					
	Greenhouse-Geisser	2977.149	39.000	76.337					
	Huynh-Feldt	2977.149	39.000	76.337					
	Lower-bound	2977.149	39.000	76.337					
Condition * Movement	Sphericity Assumed	81.711	1	81.711	3.950	.054	.092	3.950	.491
	Greenhouse-Geisser	81.711	1.000	81.711	3.950	.054	.092	3.950	.491
	Huynh-Feldt	81.711	1.000	81.711	3.950	.054	.092	3.950	.491
	Lower-bound	81.711	1.000	81.711	3.950	.054	.092	3.950	.491
Condition * Movement * Group	Sphericity Assumed	193.525	3	64.508	3.118	.037	.193	9.354	.681
	Greenhouse-Geisser	193.525	3.000	64.508	3.118	.037	.193	9.354	.681
	Huynh-Feldt	193.525	3.000	64.508	3.118	.037	.193	9.354	.681

	Lower-bound	193.525	3.000	64.508	3.118	.037	.193	9.354	.681
Error(Condition*Movement)	Sphericity Assumed	806.864	39	20.689					
	Greenhouse-Geisser	806.864	39.000	20.689					
	Huynh-Feldt	806.864	39.000	20.689					
	Lower-bound	806.864	39.000	20.689					

a. Computed using alpha = .05

Tests of Between-Subjects Effects

Measure:MEASURE_1
Transformed Variable:Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Intercept	797753.488	1	797753.488	3001.547	.000	.987	3001.547	1.000
Group	747.926	3	249.309	.938	.432	.067	2.814	.237
Error	10365.451	39	265.781					

a. Computed using alpha = .05

2. Group

Estimates

Measure:MEASURE_1

Group	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1	-67.307	2.578	-72.521	-62.094
2	-71.180	3.081	-77.412	-64.949
3	-72.931	2.261	-77.504	-68.358
4	-69.860	2.261	-74.433	-65.287

Pairwise Comparisons

Measure:MEASURE_1

(I) Group	(J) Group	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1	2	3.873	4.017	1.000	-7.293	15.039
	3	5.624	3.429	.654	-3.906	15.154
	4	2.553	3.429	1.000	-6.978	12.083
2	1	-3.873	4.017	1.000	-15.039	7.293
	3	1.751	3.821	1.000	-8.871	12.373
	4	-1.320	3.821	1.000	-11.942	9.302
3	1	-5.624	3.429	.654	-15.154	3.906
	2	-1.751	3.821	1.000	-12.373	8.871
	4	-3.071	3.197	1.000	-11.958	5.816
4	1	-2.553	3.429	1.000	-12.083	6.978
	2	1.320	3.821	1.000	-9.302	11.942
	3	3.071	3.197	1.000	-5.816	11.958

Based on estimated marginal means

a. Adjustment for multiple comparisons: Bonferroni.

3. Condition

Estimates

Measure:MEASURE_1

Condition	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1	-70.018	1.350	-72.748	-67.287
2	-70.622	1.398	-73.449	-67.795

Pairwise Comparisons

Measure:MEASURE_1

(I) Condition	(J) Condition	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1	2	.604	.981	.541	-1.379	2.588
2	1	-.604	.981	.541	-2.588	1.379

Based on estimated marginal means

a. Adjustment for multiple comparisons: Bonferroni.

4. Movement

Estimates

Measure:MEASURE_1

Movement	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1	-80.113	1.542	-83.233	-76.994
2	-60.526	1.365	-63.287	-57.766

Pairwise Comparisons

Measure:MEASURE_1

(I) Movement	(J) Movement	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1	2	-19.587*	1.376	.000	-22.370	-16.804
2	1	19.587*	1.376	.000	16.804	22.370

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

a. Adjustment for multiple comparisons: Bonferroni.

Peak Stance Knee Flexion Angle Post Hoc:

Group = 1

Tests of Within-Subjects Effects[b]

Measure:MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Condition	Sphericity Assumed	277.471	1	277.471	7.032	.026	.439	7.032	.657
	Greenhouse-Geisser	277.471	1.000	277.471	7.032	.026	.439	7.032	.657
	Huynh-Feldt	277.471	1.000	277.471	7.032	.026	.439	7.032	.657
	Lower-bound	277.471	1.000	277.471	7.032	.026	.439	7.032	.657
Error(Condition)	Sphericity Assumed	355.108	9	39.456					
	Greenhouse-Geisser	355.108	9.000	39.456					
	Huynh-Feldt	355.108	9.000	39.456					
	Lower-bound	355.108	9.000	39.456					
Movement	Sphericity Assumed	2877.611	1	2877.611	97.566	.000	.916	97.566	1.000
	Greenhouse-Geisser	2877.611	1.000	2877.611	97.566	.000	.916	97.566	1.000
	Huynh-Feldt	2877.611	1.000	2877.611	97.566	.000	.916	97.566	1.000
	Lower-bound	2877.611	1.000	2877.611	97.566	.000	.916	97.566	1.000
Error(Movement)	Sphericity Assumed	265.446	9	29.494					
	Greenhouse-Geisser	265.446	9.000	29.494					
	Huynh-Feldt	265.446	9.000	29.494					
	Lower-bound	265.446	9.000	29.494					
Condition * Movement	Sphericity Assumed	7.369	1	7.369	.702	.424	.072	.702	.117
	Greenhouse-Geisser	7.369	1.000	7.369	.702	.424	.072	.702	.117
	Huynh-Feldt	7.369	1.000	7.369	.702	.424	.072	.702	.117
	Lower-bound	7.369	1.000	7.369	.702	.424	.072	.702	.117
Error(Condition*Movement)	Sphericity Assumed	94.453	9	10.495					
	Greenhouse-Geisser	94.453	9.000	10.495					
	Huynh-Feldt	94.453	9.000	10.495					
	Lower-bound	94.453	9.000	10.495					

a. Computed using alpha =

Tests of Within-Subjects Effects[b]

Measure:MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Condition	Sphericity Assumed	277.471	1	277.471	7.032	.026	.439	7.032	.657
	Greenhouse-Geisser	277.471	1.000	277.471	7.032	.026	.439	7.032	.657
	Huynh-Feldt	277.471	1.000	277.471	7.032	.026	.439	7.032	.657
	Lower-bound	277.471	1.000	277.471	7.032	.026	.439	7.032	.657
Error(Condition)	Sphericity Assumed	355.108	9	39.456					
	Greenhouse-Geisser	355.108	9.000	39.456					
	Huynh-Feldt	355.108	9.000	39.456					
	Lower-bound	355.108	9.000	39.456					
Movement	Sphericity Assumed	2877.611	1	2877.611	97.566	.000	.916	97.566	1.000
	Greenhouse-Geisser	2877.611	1.000	2877.611	97.566	.000	.916	97.566	1.000
	Huynh-Feldt	2877.611	1.000	2877.611	97.566	.000	.916	97.566	1.000
	Lower-bound	2877.611	1.000	2877.611	97.566	.000	.916	97.566	1.000
Error(Movement)	Sphericity Assumed	265.446	9	29.494					
	Greenhouse-Geisser	265.446	9.000	29.494					
	Huynh-Feldt	265.446	9.000	29.494					
	Lower-bound	265.446	9.000	29.494					
Condition * Movement	Sphericity Assumed	7.369	1	7.369	.702	.424	.072	.702	.117
	Greenhouse-Geisser	7.369	1.000	7.369	.702	.424	.072	.702	.117
	Huynh-Feldt	7.369	1.000	7.369	.702	.424	.072	.702	.117
	Lower-bound	7.369	1.000	7.369	.702	.424	.072	.702	.117
Error(Condition*Movement)	Sphericity Assumed	94.453	9	10.495					
	Greenhouse-Geisser	94.453	9.000	10.495					
	Huynh-Feldt	94.453	9.000	10.495					
	Lower-bound	94.453	9.000	10.495					

a. Computed using alpha =

b. Group = 1

2. Condition

Estimates[a]

Measure:MEASURE_1

Condition	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1	-64.674	3.377	-72.314	-57.033
2	-69.941	3.405	-77.644	-62.238

a. Group = 1

Pairwise Comparisons[b]

Measure:MEASURE_1

(I) Condition	(J) Condition	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1	2	5.268*	1.986	.026	.774	9.761
2	1	-5.268*	1.986	.026	-9.761	-.774

Based on estimated marginal means

*. The mean difference is significant at the

a. Adjustment for multiple comparisons: Bonferroni.

b. Group = 1

3. Movement

Estimates[a]

Measure:MEASURE_1

Movement	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1	-75.789	3.338	-83.341	-68.237
2	-58.826	3.370	-66.450	-51.202

a. Group = 1

Pairwise Comparisons[b]

Measure:MEASURE_1

(I) Movement	(J) Movement	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1	2	-16.964*	1.717	.000	-20.849	-13.079
2	1	16.964*	1.717	.000	13.079	20.849

Based on estimated marginal means

*. The mean difference is significant at the

a. Adjustment for multiple comparisons: Bonferroni.

b. Group = 1

Group = 2

Tests of Within-Subjects Effects[b]

Measure:MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Condition	Sphericity Assumed	69.421	1	69.421	3.118	.128	.342	3.118	.319
	Greenhouse-Geisser	69.421	1.000	69.421	3.118	.128	.342	3.118	.319
	Huynh-Feldt	69.421	1.000	69.421	3.118	.128	.342	3.118	.319
	Lower-bound	69.421	1.000	69.421	3.118	.128	.342	3.118	.319
Error(Condition)	Sphericity Assumed	133.597	6	22.266					
	Greenhouse-Geisser	133.597	6.000	22.266					
	Huynh-Feldt	133.597	6.000	22.266					
	Lower-bound	133.597	6.000	22.266					
Movement	Sphericity Assumed	2898.829	1	2898.829	73.534	.000	.925	73.534	1.000
	Greenhouse-Geisser	2898.829	1.000	2898.829	73.534	.000	.925	73.534	1.000
	Huynh-Feldt	2898.829	1.000	2898.829	73.534	.000	.925	73.534	1.000
	Lower-bound	2898.829	1.000	2898.829	73.534	.000	.925	73.534	1.000
Error(Movement)	Sphericity Assumed	236.531	6	39.422					
	Greenhouse-Geisser	236.531	6.000	39.422					
	Huynh-Feldt	236.531	6.000	39.422					
	Lower-bound	236.531	6.000	39.422					
Condition * Movement	Sphericity Assumed	8.283	1	8.283	2.042	.203	.254	2.042	.227
	Greenhouse-Geisser	8.283	1.000	8.283	2.042	.203	.254	2.042	.227
	Huynh-Feldt	8.283	1.000	8.283	2.042	.203	.254	2.042	.227
	Lower-bound	8.283	1.000	8.283	2.042	.203	.254	2.042	.227
Error(Condition*Movement)	Sphericity Assumed	24.332	6	4.055					
	Greenhouse-Geisser	24.332	6.000	4.055					
	Huynh-Feldt	24.332	6.000	4.055					
	Lower-bound	24.332	6.000	4.055					

a. Computed using alpha =

b. Group = 2

2. Condition

Estimates[a]

Measure:MEASURE_1

Condition	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1	-72.755	2.230	-78.211	-67.299
2	-69.606	2.497	-75.717	-63.495

a. Group = 2

Pairwise Comparisons[b]

Measure:MEASURE_1

(I) Condition	(J) Condition	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1	2	-3.149	1.784	.128	-7.513	1.215
2	1	3.149	1.784	.128	-1.215	7.513

Based on estimated marginal means

a. Adjustment for multiple comparisons: Bonferroni.

b. Group = 2

3. Movement

Estimates[a]

Measure:MEASURE_1

Movement	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1	-81.355	2.683	-87.921	-74.790
2	-61.005	2.288	-66.604	-55.407

a. Group = 2

Pairwise Comparisons[b]

Measure:MEASURE_1

(I) Movement	(J) Movement	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1	2	-20.350*	2.373	.000	-26.157	-14.543
2	1	20.350*	2.373	.000	14.543	26.157

Based on estimated marginal means

*. The mean difference is significant at the

a. Adjustment for multiple comparisons: Bonferroni.

b. Group = 2

Group = 3

Tests of Within-Subjects Effects[b]

Measure:MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Condition	Sphericity Assumed	66.877	1	66.877	1.572	.234	.116	1.572	.211
	Greenhouse-Geisser	66.877	1.000	66.877	1.572	.234	.116	1.572	.211
	Huynh-Feldt	66.877	1.000	66.877	1.572	.234	.116	1.572	.211
	Lower-bound	66.877	1.000	66.877	1.572	.234	.116	1.572	.211
Error(Condition)	Sphericity Assumed	510.429	12	42.536					
	Greenhouse-Geisser	510.429	12.000	42.536					
	Huynh-Feldt	510.429	12.000	42.536					
	Lower-bound	510.429	12.000	42.536					
Movement	Sphericity Assumed	5630.626	1	5630.626	61.321	.000	.836	61.321	1.000
	Greenhouse-Geisser	5630.626	1.000	5630.626	61.321	.000	.836	61.321	1.000
	Huynh-Feldt	5630.626	1.000	5630.626	61.321	.000	.836	61.321	1.000
	Lower-bound	5630.626	1.000	5630.626	61.321	.000	.836	61.321	1.000
Error(Movement)	Sphericity Assumed	1101.863	12	91.822					
	Greenhouse-Geisser	1101.863	12.000	91.822					
	Huynh-Feldt	1101.863	12.000	91.822					
	Lower-bound	1101.863	12.000	91.822					
Condition * Movement	Sphericity Assumed	267.731	1	267.731	6.334	.027	.345	6.334	.638
	Greenhouse-Geisser	267.731	1.000	267.731	6.334	.027	.345	6.334	.638
	Huynh-Feldt	267.731	1.000	267.731	6.334	.027	.345	6.334	.638
	Lower-bound	267.731	1.000	267.731	6.334	.027	.345	6.334	.638
Error(Condition*Movement)	Sphericity Assumed	507.195	12	42.266					
	Greenhouse-Geisser	507.195	12.000	42.266					
	Huynh-Feldt	507.195	12.000	42.266					
	Lower-bound	507.195	12.000	42.266					

a. Computed using alpha =

b. Group = 3

2. Condition

Estimates[a]

Measure:MEASURE_1

Condition	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1	-71.797	1.799	-75.717	-67.877
2	-74.065	2.539	-79.598	-68.533

a. Group = 3

Pairwise Comparisons[b]

Measure:MEASURE_1

(I) Condition	(J) Condition	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1	2	2.268	1.809	.234	-1.673	6.209
2	1	-2.268	1.809	.234	-6.209	1.673

Based on estimated marginal means

a. Adjustment for multiple comparisons: Bonferroni.

b. Group = 3

3. Movement

Estimates[a]

Measure:MEASURE_1

Movement	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1	-83.337	2.587	-88.973	-77.701
2	-62.525	2.211	-67.344	-57.707

a. Group = 3

Pairwise Comparisons[b]

Measure:MEASURE_1

(I) Movement	(J) Movement	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1	2	-20.812*	2.658	.000	-26.602	-15.021
2	1	20.812*	2.658	.000	15.021	26.602

Based on estimated marginal means

*. The mean difference is significant at the

a. Adjustment for multiple comparisons: Bonferroni.

b. Group = 3

Group = 4

Tests of Within-Subjects Effects[b]

Measure:MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Condition	Sphericity Assumed	50.427	1	50.427	1.178	.299	.089	1.178	.170
	Greenhouse-Geisser	50.427	1.000	50.427	1.178	.299	.089	1.178	.170
	Huynh-Feldt	50.427	1.000	50.427	1.178	.299	.089	1.178	.170
	Lower-bound	50.427	1.000	50.427	1.178	.299	.089	1.178	.170
Error(Condition)	Sphericity Assumed	513.749	12	42.812					
	Greenhouse-Geisser	513.749	12.000	42.812					
	Huynh-Feldt	513.749	12.000	42.812					
	Lower-bound	513.749	12.000	42.812					
Movement	Sphericity Assumed	5316.554	1	5316.554	46.456	.000	.795	46.456	1.000
	Greenhouse-Geisser	5316.554	1.000	5316.554	46.456	.000	.795	46.456	1.000
	Huynh-Feldt	5316.554	1.000	5316.554	46.456	.000	.795	46.456	1.000
	Lower-bound	5316.554	1.000	5316.554	46.456	.000	.795	46.456	1.000
Error(Movement)	Sphericity Assumed	1373.309	12	114.442					
	Greenhouse-Geisser	1373.309	12.000	114.442					
	Huynh-Feldt	1373.309	12.000	114.442					
	Lower-bound	1373.309	12.000	114.442					
Condition * Movement	Sphericity Assumed	8.133	1	8.133	.540	.477	.043	.540	.104
	Greenhouse-Geisser	8.133	1.000	8.133	.540	.477	.043	.540	.104
	Huynh-Feldt	8.133	1.000	8.133	.540	.477	.043	.540	.104
	Lower-bound	8.133	1.000	8.133	.540	.477	.043	.540	.104
Error(Condition*Movement)	Sphericity Assumed	180.883	12	15.074					
	Greenhouse-Geisser	180.883	12.000	15.074					
	Huynh-Feldt	180.883	12.000	15.074					
	Lower-bound	180.883	12.000	15.074					

a. Computed using alpha =

b. Group = 4

2. Condition

Estimates[a]

Measure:MEASURE_1

Condition	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1	-70.845	2.686	-76.697	-64.992
2	-68.875	2.210	-73.690	-64.061

a. Group = 4

Pairwise Comparisons[b]

Measure:MEASURE_1

(I) Condition	(J) Condition	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1	2	-1.970	1.815	.299	-5.923	1.984
2	1	1.970	1.815	.299	-1.984	5.923

Based on estimated marginal means

a. Adjustment for multiple comparisons: Bonferroni.

b. Group = 4

3. Movement

Estimates[a]

Measure:MEASURE_1

Movement	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1	-79.971	2.987	-86.480	-73.463
2	-59.749	2.435	-65.054	-54.443

a. Group = 4

Pairwise Comparisons[b]

Measure:MEASURE_1

(I) Movement	(J) Movement	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1	2	-20.223*	2.967	.000	-26.688	-13.758
2	1	20.223*	2.967	.000	13.758	26.688

Based on estimated marginal means

*. The mean difference is significant at the

a. Adjustment for multiple comparisons: Bonferroni.

b. Group = 4

Group = 1

Paired Samples Test[a]

		Paired Differences							
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper	t	df	Sig. (2-tailed)
Pair 1	PreRtKneeXVert - Post0RtKneeXVert	6.12599100	7.32504580	2.31638287	.88596890	11.36601310	2.645	9	.027
Pair 2	PreRtKneeXAn - Post0RtKneeXAn	4.40911500	6.80046149	2.15049475	-.45564209	9.27387209	2.050	9	.071

a. Group = 1

Group = 2

Paired Samples Test[a]

		Paired Differences							
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper	t	df	Sig. (2-tailed)
Pair 1	PreRtKneeXVert - Post0RtKneeXVert	-2.06139000	4.84215014	1.83016073	-6.53963197	2.41685197	-1.126	6	.303
Pair 2	PreRtKneeXAn - Post0RtKneeXAn	-4.23694429	5.40339939	2.04229300	-9.23425524	.76036667	-2.075	6	.083

a. Group = 2

Group = 3

Paired Samples Test[a]

		Paired Differences							
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference		t	df	Sig. (2-tailed)
					Lower	Upper			
Pair 1	PreRtKneeXVert - Post0RtKneeXVert	6.80625615	12.03175613	3.33700874	-.46446131	14.07697361	2.040	12	.064
Pair 2	PreRtKneeXAn - Post0RtKneeXAn	-2.27001308	4.98407139	1.38233269	-5.28185727	.74183112	-1.642	12	.126

a. Group = 3

Group = 4

Paired Samples Test[a]

		Paired Differences							
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference		t	df	Sig. (2-tailed)
					Lower	Upper			
Pair 1	PreRtKneeXVert - Post0RtKneeXVert	-2.76045462	9.04173259	2.50772542	-8.22431894	2.70340971	-1.101	12	.293
Pair 2	PreRtKneeXAn - Post0RtKneeXAn	-1.17856154	5.83258408	1.61766777	-4.70315682	2.34603374	-.729	12	.480

a. Group = 4

Pre-Training Bilateral Landing:

NM vs. CON:

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
PreRtKneeXVert	Equal variances assumed	.038	.846	1.622	21	.120	8.62545031	5.31649047	-2.43079688	19.68169750
	Equal variances not assumed			1.657	20.708	.113	8.62545031	5.20495446	-2.20813986	19.45904048

CORE vs CON:

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
PreRtKneeXVert	Equal variances assumed	2.470	.133	-.188	18	.853	-1.03432484	5.49801520	-12.58522614	10.51657647
	Equal variances not assumed			-.224	17.987	.825	-1.03432484	4.60923972	-10.71849764	8.64984797

PLYO vs CON:

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
PreRtKneeXVert	Equal variances assumed	3.595	.070	.332	24	.743	1.41772308	4.26732867	-7.38961043	10.22505658
	Equal variances not assumed			.332	18.807	.743	1.41772308	4.26732867	-7.52010194	10.35554809

Post-Training Bilateral Landing:

NM vs CON:

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Post0RtKneeXVert	Equal variances assumed	.864	.363	-.061	21	.952	-.26099531	4.27332158	-9.14785402	8.62586341
	Equal variances not assumed			-.060	18.175	.953	-.26099531	4.34449582	-9.38213407	8.86014345

CORE vs CON:

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Post0RtKneeXVert	Equal variances assumed	.120	.733	-.409	18	.688	-1.73338945	4.24270216	-10.64697593	7.18019703
	Equal variances not assumed			-.436	14.836	.669	-1.73338945	3.97752369	-10.21942932	6.75265042

PLYO vs CON:

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Post0RtKneeXVert	Equal variances assumed	.926	.345	-1.748	24	.093	-8.14898769	4.66175899	-17.77038538	1.47240999
	Equal variances not assumed			-1.748	21.430	.095	-8.14898769	4.66175899	-17.83180866	1.53383327

Pre-Training Bilateral Landing:

Tests of Between-Subjects Effects

Dependent Variable:PreRtKneeXVert

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[b]
Corrected Model	556.777[a]	3	185.592	1.669	.190	.114	5.006	.403
Intercept	252348.654	1	252348.654	2268.744	.000	.983	2268.744	1.000
Group	556.777	3	185.592	1.669	.190	.114	5.006	.403
Error	4337.905	39	111.228					
Total	273838.871	43						
Corrected Total	4894.683	42						

a. R Squared = .114 (Adjusted R Squared = .046)

b. Computed using alpha = .05

Pre-Training Unilateral Landing:

Tests of Between-Subjects Effects

Dependent Variable:PreRtKneeXAn

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[b]
Corrected Model	320.831[a]	3	106.944	1.414	.253	.098	4.242	.345
Intercept	149761.143	1	149761.143	1980.265	.000	.981	1980.265	1.000
Group	320.831	3	106.944	1.414	.253	.098	4.242	.345
Error	2949.446	39	75.627					
Total	162914.177	43						
Corrected Total	3270.278	42						

a. R Squared = .098 (Adjusted R Squared = .029)

b. Computed using alpha = .05

Post-Training Bilateral Landing:

Tests of Between-Subjects Effects

Dependent Variable:Post0RtKneeXVert

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[b]
Corrected Model	546.299[a]	3	182.100	1.475	.236	.102	4.424	.359
Intercept	265451.658	1	265451.658	2149.743	.000	.982	2149.743	1.000
Group	546.299	3	182.100	1.475	.236	.102	4.424	.359
Error	4815.746	39	123.481					
Total	290262.374	43						
Corrected Total	5362.045	42						

a. R Squared = .102 (Adjusted R Squared = .033)

b. Computed using alpha = .05

Post-Training Unilateral Landing:

Tests of Between-Subjects Effects

Dependent Variable:Post0RtKneeXAn

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[b]
Corrected Model	51.439[a]	3	17.146	.188	.904	.014	.564	.082
Intercept	145762.014	1	145762.014	1597.167	.000	.976	1597.167	1.000
Group	51.439	3	17.146	.188	.904	.014	.564	.082
Error	3559.251	39	91.263					
Total	159571.574	43						
Corrected Total	3610.690	42						

a. R Squared = .014 (Adjusted R Squared = -.062)

b. Computed using alpha = .05

Pre-Training Unilateral Landing:

NM vs CON:

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
PreRtKneeXAn	Equal variances assumed	.765	.392	.878	21	.390	3.71669015	4.23186892	-5.08396304	12.51734334
	Equal variances not assumed			.861	17.842	.401	3.71669015	4.31864051	-5.36219069	12.79557100

CORE vs CON:

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
PreRtKneeXAn	Equal variances assumed	1.335	.263	-.703	18	.491	-2.78604813	3.96314812	-11.11231336	5.54021710
	Equal variances not assumed			-.796	17.019	.437	-2.78604813	3.49848501	-10.16656586	4.59446960

PLYO vs CON:

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
PreRtKneeXAn	Equal variances assumed	.442	.512	-1.021	24	.317	-3.32260000	3.25328991	-10.03706036	3.39186036
	Equal variances not assumed			-1.021	22.253	.318	-3.32260000	3.25328991	-10.06506424	3.41986424

Post-Training Unilateral Landing:

NM vs CON:

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Post0RtKneeXAn	Equal variances assumed	.900	.354	-.436	21	.667	-1.87098638	4.28642730	-10.78509993	7.04312716
	Equal variances not assumed			-.423	16.881	.677	-1.87098638	4.42097925	-11.20344834	7.46147557

CORE vs CON:

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Post0RtKneeXAn	Equal variances assumed	1.470	.241	.068	18	.946	.27233462	3.97607639	-8.08109190	8.62576113
	Equal variances not assumed			.074	15.425	.942	.27233462	3.67169989	-7.53498172	8.07965095

PLYO vs CON:

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Post0RtKneeXAn	Equal variances assumed	.135	.716	-.611	24	.547	-2.23114846	3.64934711	-9.76303072	5.30073379
	Equal variances not assumed			-.611	23.961	.547	-2.23114846	3.64934711	-9.76367660	5.30137967

Peak Stance Knee Abduction Angle:

Tests of Within-Subjects Effects

Measure:MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Condition	Sphericity Assumed	20.513	1	20.513	1.975	.168	.048	1.975	.278
	Greenhouse-Geisser	20.513	1.000	20.513	1.975	.168	.048	1.975	.278
	Huynh-Feldt	20.513	1.000	20.513	1.975	.168	.048	1.975	.278
	Lower-bound	20.513	1.000	20.513	1.975	.168	.048	1.975	.278
Condition * Group	Sphericity Assumed	17.962	3	5.987	.577	.634	.042	1.730	.158
	Greenhouse-Geisser	17.962	3.000	5.987	.577	.634	.042	1.730	.158
	Huynh-Feldt	17.962	3.000	5.987	.577	.634	.042	1.730	.158
	Lower-bound	17.962	3.000	5.987	.577	.634	.042	1.730	.158
Error(Condition)	Sphericity Assumed	404.981	39	10.384					
	Greenhouse-Geisser	404.981	39.000	10.384					
	Huynh-Feldt	404.981	39.000	10.384					
	Lower-bound	404.981	39.000	10.384					
Movement	Sphericity Assumed	3.061	1	3.061	1.107	.299	.028	1.107	.177
	Greenhouse-Geisser	3.061	1.000	3.061	1.107	.299	.028	1.107	.177
	Huynh-Feldt	3.061	1.000	3.061	1.107	.299	.028	1.107	.177
	Lower-bound	3.061	1.000	3.061	1.107	.299	.028	1.107	.177
Movement * Group	Sphericity Assumed	23.089	3	7.696	2.783	.054	.176	8.350	.626
	Greenhouse-Geisser	23.089	3.000	7.696	2.783	.054	.176	8.350	.626
	Huynh-Feldt	23.089	3.000	7.696	2.783	.054	.176	8.350	.626
	Lower-bound	23.089	3.000	7.696	2.783	.054	.176	8.350	.626
Error(Movement)	Sphericity Assumed	107.836	39	2.765					
	Greenhouse-Geisser	107.836	39.000	2.765					
	Huynh-Feldt	107.836	39.000	2.765					
	Lower-bound	107.836	39.000	2.765					
Condition * Movement	Sphericity Assumed	3.355	1	3.355	2.894	.097	.069	2.894	.382
	Greenhouse-Geisser	3.355	1.000	3.355	2.894	.097	.069	2.894	.382
	Huynh-Feldt	3.355	1.000	3.355	2.894	.097	.069	2.894	.382
	Lower-bound	3.355	1.000	3.355	2.894	.097	.069	2.894	.382
Condition * Movement * Group	Sphericity Assumed	4.192	3	1.397	1.205	.321	.085	3.615	.298
	Greenhouse-Geisser	4.192	3.000	1.397	1.205	.321	.085	3.615	.298
	Huynh-Feldt	4.192	3.000	1.397	1.205	.321	.085	3.615	.298
	Lower-bound	4.192	3.000	1.397	1.205	.321	.085	3.615	.298

Error(Condition*Movement)	Sphericity Assumed	45.215	39	1.159					
	Greenhouse-Geisser	45.215	39.000	1.159					
	Huynh-Feldt	45.215	39.000	1.159					
	Lower-bound	45.215	39.000	1.159					

a. Computed using alpha = .05

Tests of Between-Subjects Effects

Measure:MEASURE_1
Transformed Variable:Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Intercept	2138.469	1	2138.469	50.702	.000	.565	50.702	1.000
Group	18.925	3	6.308	.150	.929	.011	.449	.075
Error	1644.924	39	42.178					

a. Computed using alpha = .05

2. Group

Estimates

Measure:MEASURE_1

Group	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1	-3.676	1.027	-5.753	-1.599
2	-3.016	1.227	-5.498	-.533
3	-3.970	.901	-5.791	-2.148
4	-3.902	.901	-5.724	-2.080

Pairwise Comparisons

Measure:MEASURE_1

(I) Group	(J) Group	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1	2	-.660	1.600	1.000	-5.108	3.788
	3	.294	1.366	1.000	-3.502	4.091
	4	.226	1.366	1.000	-3.570	4.023
2	1	.660	1.600	1.000	-3.788	5.108
	3	.954	1.522	1.000	-3.277	5.185
	4	.886	1.522	1.000	-3.345	5.118
3	1	-.294	1.366	1.000	-4.091	3.502
	2	-.954	1.522	1.000	-5.185	3.277
	4	-.068	1.274	1.000	-3.608	3.472
4	1	-.226	1.366	1.000	-4.023	3.570
	2	-.886	1.522	1.000	-5.118	3.345
	3	.068	1.274	1.000	-3.472	3.608

Based on estimated marginal means

a. Adjustment for multiple comparisons: Bonferroni.

3. Condition

Estimates

Measure:MEASURE_1

Condition	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1	-3.284	.546	-4.389	-2.180
2	-3.997	.595	-5.200	-2.795

Pairwise Comparisons

Measure:MEASURE_1

(I) Condition	(J) Condition	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1	2	.713	.507	.168	-.313	1.739
2	1	-.713	.507	.168	-1.739	.313

Based on estimated marginal means

a. Adjustment for multiple comparisons: Bonferroni.

4. Movement

Estimates

Measure:MEASURE_1

Movement	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1	-3.779	.587	-4.967	-2.590
2	-3.503	.461	-4.435	-2.571

Pairwise Comparisons

Measure:MEASURE_1

(I) Movement	(J) Movement	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1	2	-.275	.262	.299	-.805	.254
2	1	.275	.262	.299	-.254	.805

Based on estimated marginal means

a. Adjustment for multiple comparisons: Bonferroni.

Peak Stance Hip Flexion Moment:

Tests of Within-Subjects Effects

Measure:MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Condition	Sphericity Assumed	.014	1	.014	.308	.582	.008	.308	.084
	Greenhouse-Geisser	.014	1.000	.014	.308	.582	.008	.308	.084
	Huynh-Feldt	.014	1.000	.014	.308	.582	.008	.308	.084
	Lower-bound	.014	1.000	.014	.308	.582	.008	.308	.084
Condition * Group	Sphericity Assumed	.094	3	.031	.697	.559	.050	2.092	.184
	Greenhouse-Geisser	.094	3.000	.031	.697	.559	.050	2.092	.184
	Huynh-Feldt	.094	3.000	.031	.697	.559	.050	2.092	.184
	Lower-bound	.094	3.000	.031	.697	.559	.050	2.092	.184
Error(Condition)	Sphericity Assumed	1.790	40	.045					
	Greenhouse-Geisser	1.790	40.000	.045					
	Huynh-Feldt	1.790	40.000	.045					
	Lower-bound	1.790	40.000	.045					
Movement	Sphericity Assumed	.330	1	.330	10.763	.002	.212	10.763	.893
	Greenhouse-Geisser	.330	1.000	.330	10.763	.002	.212	10.763	.893
	Huynh-Feldt	.330	1.000	.330	10.763	.002	.212	10.763	.893
	Lower-bound	.330	1.000	.330	10.763	.002	.212	10.763	.893
Movement * Group	Sphericity Assumed	.124	3	.041	1.349	.272	.092	4.048	.331
	Greenhouse-Geisser	.124	3.000	.041	1.349	.272	.092	4.048	.331
	Huynh-Feldt	.124	3.000	.041	1.349	.272	.092	4.048	.331
	Lower-bound	.124	3.000	.041	1.349	.272	.092	4.048	.331
Error(Movement)	Sphericity Assumed	1.227	40	.031					
	Greenhouse-Geisser	1.227	40.000	.031					
	Huynh-Feldt	1.227	40.000	.031					
	Lower-bound	1.227	40.000	.031					
Condition * Movement	Sphericity Assumed	.010	1	.010	.894	.350	.022	.894	.152
	Greenhouse-Geisser	.010	1.000	.010	.894	.350	.022	.894	.152
	Huynh-Feldt	.010	1.000	.010	.894	.350	.022	.894	.152
	Lower-bound	.010	1.000	.010	.894	.350	.022	.894	.152
Condition * Movement * Group	Sphericity Assumed	.027	3	.009	.832	.484	.059	2.495	.214
	Greenhouse-Geisser	.027	3.000	.009	.832	.484	.059	2.495	.214
	Huynh-Feldt	.027	3.000	.009	.832	.484	.059	2.495	.214

	Lower-bound	.027	3.000	.009	.832	.484	.059	2.495	.214
Error(Condition*Movement)	Sphericity Assumed	.433	40	.011					
	Greenhouse-Geisser	.433	40.000	.011					
	Huynh-Feldt	.433	40.000	.011					
	Lower-bound	.433	40.000	.011					

a. Computed using alpha = .05

Tests of Between-Subjects Effects

Measure:MEASURE_1
Transformed Variable:Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Intercept	153.260	1	153.260	1605.000	.000	.976	1605.000	1.000
Group	.690	3	.230	2.409	.081	.153	7.227	.559
Error	3.820	40	.095					

a. Computed using alpha = .05

2. Group

Estimates

Measure:MEASURE_1

Group	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1	-.988	.047	-1.082	-.894
2	-.912	.058	-1.030	-.794
3	-.902	.043	-.989	-.816
4	-1.051	.043	-1.138	-.965

Pairwise Comparisons

Measure:MEASURE_1

(I) Group	(J) Group	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1	2	-.076	.075	1.000	-.283	.131
	3	-.086	.063	1.000	-.261	.090
	4	.063	.063	1.000	-.112	.239
2	1	.076	.075	1.000	-.131	.283
	3	-.010	.072	1.000	-.211	.191
	4	.139	.072	.371	-.062	.340
3	1	.086	.063	1.000	-.090	.261
	2	.010	.072	1.000	-.191	.211
	4	.149	.061	.110	-.019	.317
4	1	-.063	.063	1.000	-.239	.112
	2	-.139	.072	.371	-.340	.062
	3	-.149	.061	.110	-.317	.019

Based on estimated marginal means

a. Adjustment for multiple comparisons: Bonferroni.

3. Condition

Estimates

Measure:MEASURE_1

Condition	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1	-.973	.030	-1.033	-.912
2	-.954	.028	-1.012	-.897

Pairwise Comparisons

Measure:MEASURE_1

(I) Condition	(J) Condition	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1	2	-.018	.033	.582	-.085	.048
2	1	.018	.033	.582	-.048	.085

Based on estimated marginal means

a. Adjustment for multiple comparisons: Bonferroni.

4. Movement

Estimates

Measure:MEASURE_1

Movement	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1	-.919	.023	-.966	-.871
2	-1.008	.031	-1.071	-.945

Pairwise Comparisons

Measure:MEASURE_1

(I) Movement	(J) Movement	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1	2	.089*	.027	.002	.034	.145
2	1	-.089*	.027	.002	-.145	-.034

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

a. Adjustment for multiple comparisons: Bonferroni.

Peak Stance Hip Adduction Moment:

Tests of Within-Subjects Effects

Measure:MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Condition	Sphericity Assumed	.014	1	.014	.745	.393	.018	.745	.134
	Greenhouse-Geisser	.014	1.000	.014	.745	.393	.018	.745	.134
	Huynh-Feldt	.014	1.000	.014	.745	.393	.018	.745	.134
	Lower-bound	.014	1.000	.014	.745	.393	.018	.745	.134
Condition * Group	Sphericity Assumed	.216	3	.072	3.771	.018	.220	11.312	.773
	Greenhouse-Geisser	.216	3.000	.072	3.771	.018	.220	11.312	.773
	Huynh-Feldt	.216	3.000	.072	3.771	.018	.220	11.312	.773
	Lower-bound	.216	3.000	.072	3.771	.018	.220	11.312	.773
Error(Condition)	Sphericity Assumed	.763	40	.019					
	Greenhouse-Geisser	.763	40.000	.019					
	Huynh-Feldt	.763	40.000	.019					
	Lower-bound	.763	40.000	.019					
Movement	Sphericity Assumed	4.645	1	4.645	136.373	.000	.773	136.373	1.000
	Greenhouse-Geisser	4.645	1.000	4.645	136.373	.000	.773	136.373	1.000
	Huynh-Feldt	4.645	1.000	4.645	136.373	.000	.773	136.373	1.000
	Lower-bound	4.645	1.000	4.645	136.373	.000	.773	136.373	1.000
Movement * Group	Sphericity Assumed	.368	3	.123	3.604	.021	.213	10.811	.752
	Greenhouse-Geisser	.368	3.000	.123	3.604	.021	.213	10.811	.752
	Huynh-Feldt	.368	3.000	.123	3.604	.021	.213	10.811	.752
	Lower-bound	.368	3.000	.123	3.604	.021	.213	10.811	.752
Error(Movement)	Sphericity Assumed	1.362	40	.034					
	Greenhouse-Geisser	1.362	40.000	.034					
	Huynh-Feldt	1.362	40.000	.034					
	Lower-bound	1.362	40.000	.034					
Condition * Movement	Sphericity Assumed	.006	1	.006	.654	.423	.016	.654	.124
	Greenhouse-Geisser	.006	1.000	.006	.654	.423	.016	.654	.124
	Huynh-Feldt	.006	1.000	.006	.654	.423	.016	.654	.124
	Lower-bound	.006	1.000	.006	.654	.423	.016	.654	.124
Condition * Movement * Group	Sphericity Assumed	.034	3	.011	1.145	.343	.079	3.434	.285
	Greenhouse-Geisser	.034	3.000	.011	1.145	.343	.079	3.434	.285
	Huynh-Feldt	.034	3.000	.011	1.145	.343	.079	3.434	.285

	Lower-bound	.034	3.000	.011	1.145	.343	.079	3.434	.285
Error(Condition*Movement)	Sphericity Assumed	.390	40	.010					
	Greenhouse-Geisser	.390	40.000	.010					
	Huynh-Feldt	.390	40.000	.010					
	Lower-bound	.390	40.000	.010					

a. Computed using alpha = .05

Tests of Between-Subjects Effects

Measure:MEASURE_1
Transformed Variable:Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Intercept	32.226	1	32.226	489.452	.000	.924	489.452	1.000
Group	.016	3	.005	.079	.971	.006	.236	.063
Error	2.634	40	.066					

a. Computed using alpha = .05

2. Group

Estimates

Measure:MEASURE_1

Group	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1	-.441	.039	-.519	-.363
2	-.455	.048	-.553	-.357
3	-.427	.036	-.499	-.355
4	-.444	.036	-.516	-.372

Pairwise Comparisons

Measure:MEASURE_1

(I) Group	(J) Group	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1	2	.014	.062	1.000	-.158	.186
	3	-.014	.053	1.000	-.159	.132
	4	.003	.053	1.000	-.143	.149
2	1	-.014	.062	1.000	-.186	.158
	3	-.028	.060	1.000	-.195	.139
	4	-.011	.060	1.000	-.178	.156
3	1	.014	.053	1.000	-.132	.159
	2	.028	.060	1.000	-.139	.195
	4	.017	.050	1.000	-.123	.157
4	1	-.003	.053	1.000	-.149	.143
	2	.011	.060	1.000	-.156	.178
	3	-.017	.050	1.000	-.157	.123

Based on estimated marginal means

a. Adjustment for multiple comparisons: Bonferroni.

3. Condition

Estimates

Measure:MEASURE_1

Condition	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1	-.451	.024	-.499	-.403
2	-.433	.021	-.476	-.389

Pairwise Comparisons

Measure:MEASURE_1

(I) Condition	(J) Condition	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1	2	-.019	.021	.393	-.062	.025
2	1	.019	.021	.393	-.025	.062

Based on estimated marginal means

a. Adjustment for multiple comparisons: Bonferroni.

4. Movement

Estimates

Measure:MEASURE_1

Movement	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1	-.274	.021	-.317	-.231
2	-.610	.028	-.665	-.554

Pairwise Comparisons

Measure:MEASURE_1

(I) Movement	(J) Movement	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1	2	.335*	.029	.000	.277	.394
2	1	-.335*	.029	.000	-.394	-.277

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

a. Adjustment for multiple comparisons: Bonferroni.

Peak Stance Hip Adduction Moment Post Hoc:

Group = 1

Tests of Within-Subjects Effects[b]

Measure:MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Condition	Sphericity Assumed	.004	1	.004	.285	.606	.031	.285	.077
	Greenhouse-Geisser	.004	1.000	.004	.285	.606	.031	.285	.077
	Huynh-Feldt	.004	1.000	.004	.285	.606	.031	.285	.077
	Lower-bound	.004	1.000	.004	.285	.606	.031	.285	.077
Error(Condition)	Sphericity Assumed	.124	9	.014					
	Greenhouse-Geisser	.124	9.000	.014					
	Huynh-Feldt	.124	9.000	.014					
	Lower-bound	.124	9.000	.014					
Movement	Sphericity Assumed	2.063	1	2.063	67.834	.000	.883	67.834	1.000
	Greenhouse-Geisser	2.063	1.000	2.063	67.834	.000	.883	67.834	1.000
	Huynh-Feldt	2.063	1.000	2.063	67.834	.000	.883	67.834	1.000
	Lower-bound	2.063	1.000	2.063	67.834	.000	.883	67.834	1.000
Error(Movement)	Sphericity Assumed	.274	9	.030					
	Greenhouse-Geisser	.274	9.000	.030					
	Huynh-Feldt	.274	9.000	.030					
	Lower-bound	.274	9.000	.030					
Condition * Movement	Sphericity Assumed	.005	1	.005	.709	.422	.073	.709	.117
	Greenhouse-Geisser	.005	1.000	.005	.709	.422	.073	.709	.117
	Huynh-Feldt	.005	1.000	.005	.709	.422	.073	.709	.117
	Lower-bound	.005	1.000	.005	.709	.422	.073	.709	.117
Error(Condition*Movement)	Sphericity Assumed	.069	9	.008					
	Greenhouse-Geisser	.069	9.000	.008					
	Huynh-Feldt	.069	9.000	.008					
	Lower-bound	.069	9.000	.008					

a. Computed using alpha = .05

b. Group = 1

2. Condition

Estimates[a]

Measure:MEASURE_1

Condition	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1	-.431	.033	-.505	-.358
2	-.412	.040	-.503	-.320

a. Group = 1

Pairwise Comparisons[b]

Measure:MEASURE_1

(I) Condition	(J) Condition	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1	2	-.020	.037	.606	-.104	.064
2	1	.020	.037	.606	-.064	.104

Based on estimated marginal means

a. Adjustment for multiple comparisons: Bonferroni.

b. Group = 1

3. Movement

Estimates[a]

Measure:MEASURE_1

Movement	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1	-.194	.037	-.278	-.110
2	-.649	.046	-.753	-.544

a. Group = 1

Pairwise Comparisons[b]

Measure:MEASURE_1

(I) Movement	(J) Movement	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1	2	.454*	.055	.000	.329	.579
2	1	-.454*	.055	.000	-.579	-.329

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

a. Adjustment for multiple comparisons: Bonferroni.

b. Group = 1

Group = 2

Tests of Within-Subjects Effects[b]

Measure:MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Condition	Sphericity Assumed	.023	1	.023	1.800	.228	.231	1.800	.206
	Greenhouse-Geisser	.023	1.000	.023	1.800	.228	.231	1.800	.206
	Huynh-Feldt	.023	1.000	.023	1.800	.228	.231	1.800	.206
	Lower-bound	.023	1.000	.023	1.800	.228	.231	1.800	.206
Error(Condition)	Sphericity Assumed	.077	6	.013					
	Greenhouse-Geisser	.077	6.000	.013					
	Huynh-Feldt	.077	6.000	.013					
	Lower-bound	.077	6.000	.013					
Movement	Sphericity Assumed	.321	1	.321	6.038	.049	.502	6.038	.540
	Greenhouse-Geisser	.321	1.000	.321	6.038	.049	.502	6.038	.540
	Huynh-Feldt	.321	1.000	.321	6.038	.049	.502	6.038	.540
	Lower-bound	.321	1.000	.321	6.038	.049	.502	6.038	.540
Error(Movement)	Sphericity Assumed	.319	6	.053					
	Greenhouse-Geisser	.319	6.000	.053					
	Huynh-Feldt	.319	6.000	.053					
	Lower-bound	.319	6.000	.053					
Condition * Movement	Sphericity Assumed	.001	1	.001	.081	.786	.013	.081	.057
	Greenhouse-Geisser	.001	1.000	.001	.081	.786	.013	.081	.057
	Huynh-Feldt	.001	1.000	.001	.081	.786	.013	.081	.057
	Lower-bound	.001	1.000	.001	.081	.786	.013	.081	.057
Error(Condition*Movement)	Sphericity Assumed	.069	6	.012					
	Greenhouse-Geisser	.069	6.000	.012					
	Huynh-Feldt	.069	6.000	.012					
	Lower-bound	.069	6.000	.012					

a. Computed using alpha = .05

b. Group = 2

2. Condition

Estimates[a]

Measure:MEASURE_1

Condition	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1	-.484	.054	-.615	-.352
2	-.426	.043	-.531	-.321

a. Group = 2

Pairwise Comparisons[b]

Measure:MEASURE_1

(I) Condition	(J) Condition	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1	2	-.058	.043	.228	-.163	.047
2	1	.058	.043	.228	-.047	.163

Based on estimated marginal means

a. Adjustment for multiple comparisons: Bonferroni.

b. Group = 2

3. Movement

Estimates[a]

Measure:MEASURE_1

Movement	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1	-.348	.074	-.529	-.167
2	-.562	.046	-.675	-.449

a. Group = 2

Pairwise Comparisons[b]

Measure:MEASURE_1

(I) Movement	(J) Movement	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1	2	.214*	.087	.049	.001	.428
2	1	-.214*	.087	.049	-.428	-.001

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

a. Adjustment for multiple comparisons: Bonferroni.

b. Group = 2

Group = 3

Tests of Within-Subjects Effects[b]

Measure:MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Condition	Sphericity Assumed	.088	1	.088	2.620	.131	.179	2.620	.320
	Greenhouse-Geisser	.088	1.000	.088	2.620	.131	.179	2.620	.320
	Huynh-Feldt	.088	1.000	.088	2.620	.131	.179	2.620	.320
	Lower-bound	.088	1.000	.088	2.620	.131	.179	2.620	.320
Error(Condition)	Sphericity Assumed	.403	12	.034					
	Greenhouse-Geisser	.403	12.000	.034					
	Huynh-Feldt	.403	12.000	.034					
	Lower-bound	.403	12.000	.034					
Movement	Sphericity Assumed	2.050	1	2.050	112.013	.000	.903	112.013	1.000
	Greenhouse-Geisser	2.050	1.000	2.050	112.013	.000	.903	112.013	1.000
	Huynh-Feldt	2.050	1.000	2.050	112.013	.000	.903	112.013	1.000
	Lower-bound	2.050	1.000	2.050	112.013	.000	.903	112.013	1.000
Error(Movement)	Sphericity Assumed	.220	12	.018					
	Greenhouse-Geisser	.220	12.000	.018					
	Huynh-Feldt	.220	12.000	.018					
	Lower-bound	.220	12.000	.018					
Condition * Movement	Sphericity Assumed	.001	1	.001	.078	.784	.006	.078	.058
	Greenhouse-Geisser	.001	1.000	.001	.078	.784	.006	.078	.058
	Huynh-Feldt	.001	1.000	.001	.078	.784	.006	.078	.058
	Lower-bound	.001	1.000	.001	.078	.784	.006	.078	.058
Error(Condition*Movement)	Sphericity Assumed	.143	12	.012					
	Greenhouse-Geisser	.143	12.000	.012					
	Huynh-Feldt	.143	12.000	.012					
	Lower-bound	.143	12.000	.012					

a. Computed using alpha = .05

b. Group = 3

2. Condition

Estimates[a]

Measure:MEASURE_1

Condition	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1	-.468	.048	-.573	-.364
2	-.386	.039	-.471	-.301

a. Group = 3

Pairwise Comparisons[b]

Measure:MEASURE_1

(I) Condition	(J) Condition	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1	2	-.082	.051	.131	-.193	.028
2	1	.082	.051	.131	-.028	.193

Based on estimated marginal means

a. Adjustment for multiple comparisons: Bonferroni.

b. Group = 3

3. Movement

Estimates[a]

Measure:MEASURE_1

Movement	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1	-.229	.028	-.291	-.167
2	-.626	.049	-.733	-.519

a. Group = 3

Pairwise Comparisons[b]

Measure:MEASURE_1

(I) Movement	(J) Movement	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1	2	.397*	.038	.000	.315	.479
2	1	-.397*	.038	.000	-.479	-.315

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

a. Adjustment for multiple comparisons: Bonferroni.

b. Group = 3

Group = 4

Tests of Within-Subjects Effects[b]

Measure:MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Condition	Sphericity Assumed	.105	1	.105	8.075	.015	.402	8.075	.742
	Greenhouse-Geisser	.105	1.000	.105	8.075	.015	.402	8.075	.742
	Huynh-Feldt	.105	1.000	.105	8.075	.015	.402	8.075	.742
	Lower-bound	.105	1.000	.105	8.075	.015	.402	8.075	.742
Error(Condition)	Sphericity Assumed	.157	12	.013					
	Greenhouse-Geisser	.157	12.000	.013					
	Huynh-Feldt	.157	12.000	.013					
	Lower-bound	.157	12.000	.013					
Movement	Sphericity Assumed	.958	1	.958	21.004	.001	.636	21.004	.987
	Greenhouse-Geisser	.958	1.000	.958	21.004	.001	.636	21.004	.987
	Huynh-Feldt	.958	1.000	.958	21.004	.001	.636	21.004	.987
	Lower-bound	.958	1.000	.958	21.004	.001	.636	21.004	.987
Error(Movement)	Sphericity Assumed	.547	12	.046					
	Greenhouse-Geisser	.547	12.000	.046					
	Huynh-Feldt	.547	12.000	.046					
	Lower-bound	.547	12.000	.046					
Condition * Movement	Sphericity Assumed	.043	1	.043	7.270	.019	.377	7.270	.697
	Greenhouse-Geisser	.043	1.000	.043	7.270	.019	.377	7.270	.697
	Huynh-Feldt	.043	1.000	.043	7.270	.019	.377	7.270	.697
	Lower-bound	.043	1.000	.043	7.270	.019	.377	7.270	.697
Error(Condition*Movement)	Sphericity Assumed	.072	12	.006					
	Greenhouse-Geisser	.072	12.000	.006					
	Huynh-Feldt	.072	12.000	.006					
	Lower-bound	.072	12.000	.006					

a. Computed using alpha = .05

b. Group = 4

2. Condition

Estimates[a]

Measure:MEASURE_1

Condition	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1	-.399	.045	-.497	-.301
2	-.489	.041	-.579	-.400

a. Group = 4

Pairwise Comparisons[b]

Measure:MEASURE_1

(I) Condition	(J) Condition	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1	2	.090*	.032	.015	.021	.159
2	1	-.090*	.032	.015	-.159	-.021

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

a. Adjustment for multiple comparisons: Bonferroni.

b. Group = 4

3. Movement

Estimates[a]

Measure:MEASURE_1

Movement	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1	-.308	.038	-.391	-.226
2	-.580	.059	-.709	-.451

a. Group = 4

Pairwise Comparisons[b]

Measure:MEASURE_1

(I) Movement	(J) Movement	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1	2	.271*	.059	.001	.142	.400
2	1	-.271*	.059	.001	-.400	-.142

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

a. Adjustment for multiple comparisons: Bonferroni.

b. Group = 4

Peak Stance Knee Flexion Moment:

Tests of Within-Subjects Effects

Measure:MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Condition	Sphericity Assumed	.069	1	.069	2.100	.155	.050	2.100	.293
	Greenhouse-Geisser	.069	1.000	.069	2.100	.155	.050	2.100	.293
	Huynh-Feldt	.069	1.000	.069	2.100	.155	.050	2.100	.293
	Lower-bound	.069	1.000	.069	2.100	.155	.050	2.100	.293
Condition * Group	Sphericity Assumed	.108	3	.036	1.095	.362	.076	3.285	.273
	Greenhouse-Geisser	.108	3.000	.036	1.095	.362	.076	3.285	.273
	Huynh-Feldt	.108	3.000	.036	1.095	.362	.076	3.285	.273
	Lower-bound	.108	3.000	.036	1.095	.362	.076	3.285	.273
Error(Condition)	Sphericity Assumed	1.317	40	.033					
	Greenhouse-Geisser	1.317	40.000	.033					
	Huynh-Feldt	1.317	40.000	.033					
	Lower-bound	1.317	40.000	.033					
Movement	Sphericity Assumed	6.055	1	6.055	120.643	.000	.751	120.643	1.000
	Greenhouse-Geisser	6.055	1.000	6.055	120.643	.000	.751	120.643	1.000
	Huynh-Feldt	6.055	1.000	6.055	120.643	.000	.751	120.643	1.000
	Lower-bound	6.055	1.000	6.055	120.643	.000	.751	120.643	1.000
Movement * Group	Sphericity Assumed	.050	3	.017	.331	.803	.024	.994	.109
	Greenhouse-Geisser	.050	3.000	.017	.331	.803	.024	.994	.109
	Huynh-Feldt	.050	3.000	.017	.331	.803	.024	.994	.109
	Lower-bound	.050	3.000	.017	.331	.803	.024	.994	.109
Error(Movement)	Sphericity Assumed	2.008	40	.050					
	Greenhouse-Geisser	2.008	40.000	.050					
	Huynh-Feldt	2.008	40.000	.050					
	Lower-bound	2.008	40.000	.050					
Condition * Movement	Sphericity Assumed	.001	1	.001	.027	.870	.001	.027	.053
	Greenhouse-Geisser	.001	1.000	.001	.027	.870	.001	.027	.053
	Huynh-Feldt	.001	1.000	.001	.027	.870	.001	.027	.053
	Lower-bound	.001	1.000	.001	.027	.870	.001	.027	.053
Condition * Movement * Group	Sphericity Assumed	.085	3	.028	1.516	.225	.102	4.547	.369
	Greenhouse-Geisser	.085	3.000	.028	1.516	.225	.102	4.547	.369
	Huynh-Feldt	.085	3.000	.028	1.516	.225	.102	4.547	.369

	Lower-bound	.085	3.000	.028	1.516	.225	.102	4.547	.369
Error(Condition*Movement)	Sphericity Assumed	.749	40	.019					
	Greenhouse-Geisser	.749	40.000	.019					
	Huynh-Feldt	.749	40.000	.019					
	Lower-bound	.749	40.000	.019					

a. Computed using alpha = .05

Tests of Between-Subjects Effects

Measure:MEASURE_1
Transformed Variable:Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Intercept	302.512	1	302.512	2104.715	.000	.981	2104.715	1.000
Group	.677	3	.226	1.571	.211	.105	4.713	.382
Error	5.749	40	.144					

a. Computed using alpha = .05

2. Group

Estimates

Measure:MEASURE_1

Group	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1	1.306	.057	1.191	1.422
2	1.282	.072	1.137	1.427
3	1.383	.053	1.277	1.489
4	1.443	.053	1.337	1.549

Pairwise Comparisons

Measure:MEASURE_1

(I) Group	(J) Group	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1	2	.024	.092	1.000	-.230	.279
	3	-.077	.078	1.000	-.292	.139
	4	-.137	.078	.517	-.352	.079
2	1	-.024	.092	1.000	-.279	.230
	3	-.101	.089	1.000	-.348	.146
	4	-.161	.089	.466	-.408	.086
3	1	.077	.078	1.000	-.139	.292
	2	.101	.089	1.000	-.146	.348
	4	-.060	.074	1.000	-.266	.147
4	1	.137	.078	.517	-.079	.352
	2	.161	.089	.466	-.086	.408
	3	.060	.074	1.000	-.147	.266

Based on estimated marginal means

a. Adjustment for multiple comparisons: Bonferroni.

3. Condition

Estimates

Measure:MEASURE_1

Condition	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1	1.333	.033	1.266	1.400
2	1.374	.032	1.309	1.440

Pairwise Comparisons

Measure:MEASURE_1

(I) Condition	(J) Condition	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1	2	-.041	.028	.155	-.098	.016
2	1	.041	.028	.155	-.016	.098

Based on estimated marginal means

a. Adjustment for multiple comparisons: Bonferroni.

4. Movement

Estimates

Measure:MEASURE_1

Movement	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1	1.162	.034	1.093	1.231
2	1.545	.034	1.476	1.615

Pairwise Comparisons

Measure:MEASURE_1

(I) Movement	(J) Movement	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1	2	-.383*	.035	.000	-.453	-.313
2	1	.383*	.035	.000	.313	.453

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

a. Adjustment for multiple comparisons: Bonferroni.

Peak Stance Knee Abduction Moment:

Tests of Within-Subjects Effects

Measure:MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power^a
Condition	Sphericity Assumed	.020	1	.020	2.249	.142	.053	2.249	.310
	Greenhouse-Geisser	.020	1.000	.020	2.249	.142	.053	2.249	.310
	Huynh-Feldt	.020	1.000	.020	2.249	.142	.053	2.249	.310
	Lower-bound	.020	1.000	.020	2.249	.142	.053	2.249	.310
Condition * Group	Sphericity Assumed	.094	3	.031	3.579	.022	.212	10.736	.749
	Greenhouse-Geisser	.094	3.000	.031	3.579	.022	.212	10.736	.749
	Huynh-Feldt	.094	3.000	.031	3.579	.022	.212	10.736	.749
	Lower-bound	.094	3.000	.031	3.579	.022	.212	10.736	.749
Error(Condition)	Sphericity Assumed	.351	40	.009					
	Greenhouse-Geisser	.351	40.000	.009					
	Huynh-Feldt	.351	40.000	.009					
	Lower-bound	.351	40.000	.009					
Movement	Sphericity Assumed	.012	1	.012	.359	.552	.009	.359	.090
	Greenhouse-Geisser	.012	1.000	.012	.359	.552	.009	.359	.090
	Huynh-Feldt	.012	1.000	.012	.359	.552	.009	.359	.090
	Lower-bound	.012	1.000	.012	.359	.552	.009	.359	.090
Movement * Group	Sphericity Assumed	.063	3	.021	.652	.586	.047	1.955	.174
	Greenhouse-Geisser	.063	3.000	.021	.652	.586	.047	1.955	.174
	Huynh-Feldt	.063	3.000	.021	.652	.586	.047	1.955	.174
	Lower-bound	.063	3.000	.021	.652	.586	.047	1.955	.174
Error(Movement)	Sphericity Assumed	1.282	40	.032					
	Greenhouse-Geisser	1.282	40.000	.032					
	Huynh-Feldt	1.282	40.000	.032					
	Lower-bound	1.282	40.000	.032					
Condition * Movement	Sphericity Assumed	.007	1	.007	1.106	.299	.027	1.106	.177
	Greenhouse-Geisser	.007	1.000	.007	1.106	.299	.027	1.106	.177
	Huynh-Feldt	.007	1.000	.007	1.106	.299	.027	1.106	.177
	Lower-bound	.007	1.000	.007	1.106	.299	.027	1.106	.177
Condition * Movement * Group	Sphericity Assumed	.063	3	.021	3.158	.035	.191	9.474	.689
	Greenhouse-Geisser	.063	3.000	.021	3.158	.035	.191	9.474	.689
	Huynh-Feldt	.063	3.000	.021	3.158	.035	.191	9.474	.689

	Lower-bound	.063	3.000	.021	3.158	.035	.191	9.474	.689
Error(Condition*Movement)	Sphericity Assumed	.266	40	.007					
	Greenhouse-Geisser	.266	40.000	.007					
	Huynh-Feldt	.266	40.000	.007					
	Lower-bound	.266	40.000	.007					

a. Computed using alpha = .05

Tests of Between-Subjects Effects

Measure:MEASURE_1
Transformed Variable:Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Intercept	23.778	1	23.778	413.575	.000	.912	413.575	1.000
Group	.121	3	.040	.699	.558	.050	2.098	.185
Error	2.300	40	.057					

a. Computed using alpha = .05

2. Group

Estimates

Measure:MEASURE_1

Group	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1	.410	.036	.337	.483
2	.358	.045	.267	.450
3	.350	.033	.283	.417
4	.399	.033	.332	.467

Pairwise Comparisons

Measure:MEASURE_1

(I) Group	(J) Group	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1	2	.052	.058	1.000	-.109	.213
	3	.061	.049	1.000	-.076	.197
	4	.011	.049	1.000	-.125	.147
2	1	-.052	.058	1.000	-.213	.109
	3	.009	.056	1.000	-.147	.165
	4	-.041	.056	1.000	-.197	.115
3	1	-.061	.049	1.000	-.197	.076
	2	-.009	.056	1.000	-.165	.147
	4	-.050	.047	1.000	-.180	.081
4	1	-.011	.049	1.000	-.147	.125
	2	.041	.056	1.000	-.115	.197
	3	.050	.047	1.000	-.081	.180

Based on estimated marginal means

a. Adjustment for multiple comparisons: Bonferroni.

3. Condition

Estimates

Measure:MEASURE_1

Condition	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1	.390	.019	.352	.428
2	.369	.021	.326	.411

Pairwise Comparisons

Measure:MEASURE_1

(I) Condition	(J) Condition	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1	2	.022	.015	.142	-.008	.051
2	1	-.022	.015	.142	-.051	.008

Based on estimated marginal means

a. Adjustment for multiple comparisons: Bonferroni.

4. Movement

Estimates

Measure:MEASURE_1

Movement	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1	.371	.022	.326	.416
2	.388	.024	.339	.437

Pairwise Comparisons

Measure:MEASURE_1

(I) Movement	(J) Movement	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1	2	-.017	.028	.552	-.073	.040
2	1	.017	.028	.552	-.040	.073

Based on estimated marginal means

a. Adjustment for multiple comparisons: Bonferroni.

Peak Stance Knee Abduction Moment Post Hoc:

Group = 1

Tests of Within-Subjects Effects[b]

Measure:MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Condition	Sphericity Assumed	.001	1	.001	.179	.682	.019	.179	.067
	Greenhouse-Geisser	.001	1.000	.001	.179	.682	.019	.179	.067
	Huynh-Feldt	.001	1.000	.001	.179	.682	.019	.179	.067
	Lower-bound	.001	1.000	.001	.179	.682	.019	.179	.067
Error(Condition)	Sphericity Assumed	.066	9	.007					
	Greenhouse-Geisser	.066	9.000	.007					
	Huynh-Feldt	.066	9.000	.007					
	Lower-bound	.066	9.000	.007					
Movement	Sphericity Assumed	.002	1	.002	.063	.808	.007	.063	.056
	Greenhouse-Geisser	.002	1.000	.002	.063	.808	.007	.063	.056
	Huynh-Feldt	.002	1.000	.002	.063	.808	.007	.063	.056
	Lower-bound	.002	1.000	.002	.063	.808	.007	.063	.056
Error(Movement)	Sphericity Assumed	.283	9	.031					
	Greenhouse-Geisser	.283	9.000	.031					
	Huynh-Feldt	.283	9.000	.031					
	Lower-bound	.283	9.000	.031					
Condition * Movement	Sphericity Assumed	.001	1	.001	.088	.773	.010	.088	.058
	Greenhouse-Geisser	.001	1.000	.001	.088	.773	.010	.088	.058
	Huynh-Feldt	.001	1.000	.001	.088	.773	.010	.088	.058
	Lower-bound	.001	1.000	.001	.088	.773	.010	.088	.058
Error(Condition*Movement)	Sphericity Assumed	.069	9	.008					
	Greenhouse-Geisser	.069	9.000	.008					
	Huynh-Feldt	.069	9.000	.008					
	Lower-bound	.069	9.000	.008					

a. Computed using alpha = .05

b. Group = 1

2. Condition

Estimates[a]

Measure:MEASURE_1

Condition	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1	.416	.037	.333	.499
2	.404	.034	.327	.481

a. Group = 1

Pairwise Comparisons[b]

Measure:MEASURE_1

(I) Condition	(J) Condition	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1	2	.011	.027	.682	-.050	.073
2	1	-.011	.027	.682	-.073	.050

Based on estimated marginal means

a. Adjustment for multiple comparisons: Bonferroni.

b. Group = 1

3. Movement

Estimates[a]

Measure:MEASURE_1

Movement	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1	.417	.046	.314	.520
2	.403	.040	.312	.494

a. Group = 1

Pairwise Comparisons[b]

Measure:MEASURE_1

(I) Movement	(J) Movement	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1	2	.014	.056	.808	-.113	.141
2	1	-.014	.056	.808	-.141	.113

Based on estimated marginal means

a. Adjustment for multiple comparisons: Bonferroni.

b. Group = 1

Group = 2

Tests of Within-Subjects Effects[b]

Measure:MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Condition	Sphericity Assumed	.020	1	.020	.796	.407	.117	.796	.118
	Greenhouse-Geisser	.020	1.000	.020	.796	.407	.117	.796	.118
	Huynh-Feldt	.020	1.000	.020	.796	.407	.117	.796	.118
	Lower-bound	.020	1.000	.020	.796	.407	.117	.796	.118
Error(Condition)	Sphericity Assumed	.148	6	.025					
	Greenhouse-Geisser	.148	6.000	.025					
	Huynh-Feldt	.148	6.000	.025					
	Lower-bound	.148	6.000	.025					
Movement	Sphericity Assumed	.002	1	.002	.068	.803	.011	.068	.056
	Greenhouse-Geisser	.002	1.000	.002	.068	.803	.011	.068	.056
	Huynh-Feldt	.002	1.000	.002	.068	.803	.011	.068	.056
	Lower-bound	.002	1.000	.002	.068	.803	.011	.068	.056
Error(Movement)	Sphericity Assumed	.138	6	.023					
	Greenhouse-Geisser	.138	6.000	.023					
	Huynh-Feldt	.138	6.000	.023					
	Lower-bound	.138	6.000	.023					
Condition * Movement	Sphericity Assumed	.002	1	.002	.377	.562	.059	.377	.082
	Greenhouse-Geisser	.002	1.000	.002	.377	.562	.059	.377	.082
	Huynh-Feldt	.002	1.000	.002	.377	.562	.059	.377	.082
	Lower-bound	.002	1.000	.002	.377	.562	.059	.377	.082
Error(Condition*Movement)	Sphericity Assumed	.024	6	.004					
	Greenhouse-Geisser	.024	6.000	.004					
	Huynh-Feldt	.024	6.000	.004					
	Lower-bound	.024	6.000	.004					

a. Computed using alpha = .05

b. Group = 2

2. Condition

Estimates[a]

Measure:MEASURE_1

Condition	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1	.332	.042	.230	.434
2	.385	.084	.179	.591

a. Group = 2

Pairwise Comparisons[b]

Measure:MEASURE_1

(I) Condition	(J) Condition	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1	2	-.053	.059	.407	-.198	.092
2	1	.053	.059	.407	-.092	.198

Based on estimated marginal means

a. Adjustment for multiple comparisons: Bonferroni.

b. Group = 2

3. Movement

Estimates[a]

Measure:MEASURE_1

Movement	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1	.351	.044	.243	.459
2	.366	.082	.165	.567

a. Group = 2

Pairwise Comparisons[b]

Measure:MEASURE_1

(I) Movement	(J) Movement	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1	2	-.015	.057	.803	-.155	.125
2	1	.015	.057	.803	-.125	.155

Based on estimated marginal means

a. Adjustment for multiple comparisons: Bonferroni.

b. Group = 2

Group = 3

Tests of Within-Subjects Effects[b]

Measure:MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Condition	Sphericity Assumed	.016	1	.016	4.751	.050	.284	4.751	.518
	Greenhouse-Geisser	.016	1.000	.016	4.751	.050	.284	4.751	.518
	Huynh-Feldt	.016	1.000	.016	4.751	.050	.284	4.751	.518
	Lower-bound	.016	1.000	.016	4.751	.050	.284	4.751	.518
Error(Condition)	Sphericity Assumed	.040	12	.003					
	Greenhouse-Geisser	.040	12.000	.003					
	Huynh-Feldt	.040	12.000	.003					
	Lower-bound	.040	12.000	.003					
Movement	Sphericity Assumed	.059	1	.059	3.606	.082	.231	3.606	.416
	Greenhouse-Geisser	.059	1.000	.059	3.606	.082	.231	3.606	.416
	Huynh-Feldt	.059	1.000	.059	3.606	.082	.231	3.606	.416
	Lower-bound	.059	1.000	.059	3.606	.082	.231	3.606	.416
Error(Movement)	Sphericity Assumed	.196	12	.016					
	Greenhouse-Geisser	.196	12.000	.016					
	Huynh-Feldt	.196	12.000	.016					
	Lower-bound	.196	12.000	.016					
Condition * Movement	Sphericity Assumed	.015	1	.015	2.839	.118	.191	2.839	.342
	Greenhouse-Geisser	.015	1.000	.015	2.839	.118	.191	2.839	.342
	Huynh-Feldt	.015	1.000	.015	2.839	.118	.191	2.839	.342
	Lower-bound	.015	1.000	.015	2.839	.118	.191	2.839	.342
Error(Condition*Movement)	Sphericity Assumed	.064	12	.005					
	Greenhouse-Geisser	.064	12.000	.005					
	Huynh-Feldt	.064	12.000	.005					
	Lower-bound	.064	12.000	.005					

a. Computed using alpha = .05

b. Group = 3

2. Condition

Estimates[a]

Measure:MEASURE_1

Condition	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1	.367	.031	.299	.436
2	.332	.031	.265	.400

a. Group = 3

Pairwise Comparisons[b]

Measure:MEASURE_1

(I) Condition	(J) Condition	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1	2	.035*	.016	.050	1.406E-5	.070
2	1	-.035*	.016	.050	-.070	-1.406E-5

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

a. Adjustment for multiple comparisons: Bonferroni.

b. Group = 3

3. Movement

Estimates[a]

Measure:MEASURE_1

Movement	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1	.316	.032	.247	.385
2	.383	.038	.301	.466

a. Group = 3

Pairwise Comparisons[b]

Measure:MEASURE_1

(I) Movement	(J) Movement	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1	2	-.067	.035	.082	-.145	.010
2	1	.067	.035	.082	-.010	.145

Based on estimated marginal means

a. Adjustment for multiple comparisons: Bonferroni.

b. Group = 3

Group = 4

Tests of Within-Subjects Effects[b]

Measure:MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Condition	Sphericity Assumed	.101	1	.101	13.090	.004	.522	13.090	.913
	Greenhouse-Geisser	.101	1.000	.101	13.090	.004	.522	13.090	.913
	Huynh-Feldt	.101	1.000	.101	13.090	.004	.522	13.090	.913
	Lower-bound	.101	1.000	.101	13.090	.004	.522	13.090	.913
Error(Condition)	Sphericity Assumed	.093	12	.008					
	Greenhouse-Geisser	.093	12.000	.008					
	Huynh-Feldt	.093	12.000	.008					
	Lower-bound	.093	12.000	.008					
Movement	Sphericity Assumed	.005	1	.005	.097	.761	.008	.097	.060
	Greenhouse-Geisser	.005	1.000	.005	.097	.761	.008	.097	.060
	Huynh-Feldt	.005	1.000	.005	.097	.761	.008	.097	.060
	Lower-bound	.005	1.000	.005	.097	.761	.008	.097	.060
Error(Movement)	Sphericity Assumed	.616	12	.051					
	Greenhouse-Geisser	.616	12.000	.051					
	Huynh-Feldt	.616	12.000	.051					
	Lower-bound	.616	12.000	.051					
Condition * Movement	Sphericity Assumed	.053	1	.053	5.889	.032	.329	5.889	.607
	Greenhouse-Geisser	.053	1.000	.053	5.889	.032	.329	5.889	.607
	Huynh-Feldt	.053	1.000	.053	5.889	.032	.329	5.889	.607
	Lower-bound	.053	1.000	.053	5.889	.032	.329	5.889	.607
Error(Condition*Movement)	Sphericity Assumed	.109	12	.009					
	Greenhouse-Geisser	.109	12.000	.009					
	Huynh-Feldt	.109	12.000	.009					
	Lower-bound	.109	12.000	.009					

a. Computed using alpha = .05

b. Group = 4

2. Condition

Estimates[a]

Measure:MEASURE_1

Condition	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1	.443	.039	.359	.528
2	.355	.035	.279	.431

a. Group = 4

Pairwise Comparisons[b]

Measure:MEASURE_1

(I) Condition	(J) Condition	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1	2	.088*	.024	.004	.035	.141
2	1	-.088*	.024	.004	-.141	-.035

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

a. Adjustment for multiple comparisons: Bonferroni.

b. Group = 4

3. Movement

Estimates[a]

Measure:MEASURE_1

Movement	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1	.390	.049	.284	.496
2	.409	.045	.311	.507

a. Group = 4

Pairwise Comparisons[b]

Measure:MEASURE_1

(I) Movement	(J) Movement	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1	2	-.020	.063	.761	-.157	.117
2	1	.020	.063	.761	-.117	.157

Based on estimated marginal means

a. Adjustment for multiple comparisons: Bonferroni.

b. Group = 4

Pre-Training Bilateral Landing:

Tests of Between-Subjects Effects

Dependent Variable:PreRtKneeYVert

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[b]
Corrected Model	.059[a]	3	.020	.811	.495	.059	2.434	.209
Intercept	5.581	1	5.581	228.859	.000	.854	228.859	1.000
Group	.059	3	.020	.811	.495	.059	2.434	.209
Error	.951	39	.024					
Total	7.102	43						
Corrected Total	1.010	42						

a. R Squared = .059 (Adjusted R Squared = -.014)
b. Computed using alpha = .05

Post-Training Bilateral Landing:

Tests of Between-Subjects Effects

Dependent Variable:Post0RtKneeYVert

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[b]
Corrected Model	.119[a]	3	.040	1.706	.182	.116	5.117	.411
Intercept	5.368	1	5.368	231.149	.000	.856	231.149	1.000
Group	.119	3	.040	1.706	.182	.116	5.117	.411
Error	.906	39	.023					
Total	6.551	43						
Corrected Total	1.024	42						

a. R Squared = .116 (Adjusted R Squared = .048)
b. Computed using alpha = .05

Pre-Training Unilateral Landing:

Tests of Between-Subjects Effects

Dependent Variable:PreRtKneeYAn

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[b]
Corrected Model	.110[a]	3	.037	1.174	.332	.083	3.521	.291
Intercept	6.687	1	6.687	214.932	.000	.846	214.932	1.000
Group	.110	3	.037	1.174	.332	.083	3.521	.291
Error	1.213	39	.031					
Total	8.736	43						
Corrected Total	1.323	42						

a. R Squared = .083 (Adjusted R Squared = .012)
b. Computed using alpha = .05

Post-Training Unilateral Landing:

Tests of Between-Subjects Effects

Dependent Variable:Post0RtKneeYAn

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[b]
Corrected Model	.027[a]	3	.009	.326	.807	.024	.978	.108
Intercept	5.628	1	5.628	204.047	.000	.840	204.047	1.000
Group	.027	3	.009	.326	.807	.024	.978	.108
Error	1.076	39	.028					
Total	7.008	43						
Corrected Total	1.103	42						

a. R Squared = .024 (Adjusted R Squared = -.051)
b. Computed using alpha = .05

Group = 1

Paired Samples Test[a]

		Paired Differences					t	df	Sig. (2-tailed)
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Pair 1	PreRtKneeYVert - Post0RtKneeYVert	.00321800	.14031745	.04437227	-.09715905	.10359505	.073	9	.944
Pair 2	PreRtKneeYAn - Post0RtKneeYAn	.01971500	.10196956	.03224561	-.05322963	.09265963	.611	9	.556

a. Group = 1

Group = 2

Paired Samples Test[a]

		Paired Differences					t	df	Sig. (2-tailed)
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Pair 1	PreRtKneeYVert - Post0RtKneeYVert	-.06764286	.15893975	.06007358	-.21463761	.07935190	-1.126	6	.303
Pair 2	PreRtKneeYAn - Post0RtKneeYAn	-.03835000	.17923808	.06774563	-.20411758	.12741758	-.566	6	.592

a. Group = 2

Group = 3

Paired Samples Test[a]

		Paired Differences					t	df	Sig. (2-tailed)
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Pair 1	PreRtKneeYVert - Post0RtKneeYVert	.06898462	.09707245	.02692305	.01032432	.12764491	2.562	12	.025
Pair 2	PreRtKneeYAn - Post0RtKneeYAn	.00078769	.08878990	.02462589	-.05286751	.05444289	.032	12	.975

a. Group = 3

Group = 4

Paired Samples Test[a]

		Paired Differences					t	df	Sig. (2-tailed)
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Pair 1	PreRtKneeYVert - Post0RtKneeYVert	.02417769	.08992122	.02493966	-.03016116	.07851654	.969	12	.351
Pair 2	PreRtKneeYAn - Post0RtKneeYAn	.15232846	.15971675	.04429746	.05581260	.24884433	3.439	12	.005

a. Group = 4

Table E.13. Mean knee kinematic, kinetic and muscle activation data during unilateral landings for Aim 4.

	Angle				Moment					Pre-Activity				
	Hip		Knee		Hip		Knee		Knee					
Subj ID	**Flx**	**Add**	**Flx**	**Abd**	**Flx**	**Add**	**Flx**	**Abd**	**Ant**	**VL**	**RF**	**LH**	**GM**	**VL:LH**
1	-9.67	-0.42	9.22	-1.09	0.48	-0.22	0.43	-0.48	-1.19	-0.95	-0.17	-0.17	0.86	-18.75
8	2.68	8.85	-4.16	-2.95	-0.45	-0.36	0.03	-0.08	-0.65	-2.58		0.04	0.25	-11.8
16	-5.41	-9.19	-0.28	-4.18	0.04	0	-0.15	-0.04	0.37	-1.93	-0.2	0.11	0.38	18.68
34	-9.05	-20.26	-2.87	2.87	0.3	0.58	0.18	0.15	-0.01	0.04	-0.08		1.05	
35	-3.09	-1.91	14.59	5.18	0.05	0.06	0.26	-0.03	0.84	-0.17	-0.05	-0.48	-0.34	-63.86
36	3.81	6.59	-0.05	-5.97	0.09	0.16	-0.07	0.36	-0.32	-0.58	-0.26	-0.04	-0.46	4.18
38	1.58	1.97	4.89	0.69	-0.13	-0.07	0.19	0.01	1.04	0.59	0.22	0.06	-0.13	6.22
39	0.57	-9.26	9.21	-1.89	0.32	0.25	0.31	0.08	0.22	-0.12	-0.38	-0.23	-0.57	-42.02
40	9.02	3.58	-7.58	1.08	0.14	0.15	-0.13	0	-0.4	-0.07	-0.21	0.05	0.28	12.71
41	11.76	-0.61	-6.35	-2.14	-0.29	0.2	0.06	0.14	1.51	-0.36	0.01	0.05	-0.09	16.27
43	0.42	4.62	-4.36	-0.74	0.5	-0.1	-0.04	-0.19	-0.72	-0.51	-0.22	-0.53	-0.54	-80.83
49	15.93	14.64	-13.22	-3.55	0.08	0.06	0.02	-0.06	0.92	0.41	0.09	-0.11	-0.49	-19.32
50	11.39	-4.85	4.32	1.88	0.33	-0.01	0.11	-0.08	-0.84	-0.41	-0.05	0.06	-0.22	11.94
51	4.9	3.77	-7.56	0.89	0.18	0.2	0.46	-0.08	-1.09	0.03	-0.27	-0.55	0.06	-74.41
52	-0.43	-9.28	-9.47	2.71	0.22	-0.17	0.34	0.01	0.58	-0.15	-0.12	-0.09	-0.03	-15.02
53	-9.07	-13.87	-1.41	0.78	-0.16	0.01	-0.02	-0.02	-0.41	0.23	0.03	0.12	-0.14	19.41
54	1.68	1.6	-7.47	-1.83	0.15	-0.02	0.19	-0.02	-0.92	-1.65	-0.28	-0.19	-0.39	-21.29
59	8.11	1.98	0.53	2.66	-0.18	0.04	0.11	-0.01	-0.1	0.11	0.08	-0.27	-0.24	-50.42
60	5.63	-4.92	-3.54	-5.38	-0.29	0.06	-0.51	-0.12	1.29	-0.69	0.1	0.17	0.14	15.44
61	-6.39	10.54	-13.33	0.4	-0.19	-0.22	-0.05	-0.02	-0.48	0.63	0.11	0.12		20.55
62	-5.59	-4.89	3.03	3.87	-0.23	0.03	0.03	-0.01	0.11	0.41	0	0.14	0.06	18.29
63	-6.29	3.21	6.03	-2.09	-0.01	-0.12	0.11	0.02	-0.01	0.2		-0.07	0.08	-10.91
64	-7.53	-2.73	0.82	-6.28	0.02	-0.17	0.23	0.01	-0.24	0.26			-0.41	
65	-5.27	-15.47	11.5	-2.13	-0.01	0.48	0.08	0.09	0.44	-0.55	0.17	0.05	0.22	16.3

Table E.13. cont’d

	Angle				Moment					Pre-Activity				
	Hip		Knee		Hip		Knee		Knee					
Subj ID	**Flx**	**Add**	**Flx**	**Abd**	**Flx**	**Add**	**Flx**	**Abd**	**Ant**	**VL**	**RF**	**LH**	**GM**	**VL:LH**
67	5.88	-2.61	-0.08	-0.08	0.02	0.4	0.03	0.1	0.54	0.19	0.09	0.13	-0.23	19.47
68	6.73	-6.94	4.21	1.39	-0.19	-0.04	-0.28	0.07	0.38	-0.12	0.08	-0.02	-0.08	-4.22
74	7.29	-3.84	11.01	4.94	-0.15	0.02	0.08	0	0.19	-0.97	0.01	0.55	0.87	76.42
7	-0.57	-4.05	-2.51	-4.37	0.02	-0.14	-0.36	-0.09	0.37	-0.94	-0.15	-0.02	-0.15	2.45
12	-2.24	-5.32	2.7	-1.38	0.23	-0.07	-0.37	-0.4	0.71	-0.38		0	0.14	3.28
14	-6.87	3.39	-0.32	-0.24	0.04	-0.29	0.15	-0.34	-0.82	-0.23	-0.5	0.01	-0.44	1.17
15	-4.05	-7.91	13.04	-2.18	0.14	-0.36	-0.27	-0.17	0.42	-0.24		0.02	0.49	3.53
45	-2.62	-3.67	-0.32	-2.85	0.26	0.4	0.46	-0.07	0.48	-0.98	-0.07	0.1	0.18	20.18
46	3.65	2.52	-1.92	3	-0.07	0.06	0.07	-0.15	0.82	-1.19	-0.06	0.06	-0.23	23.14
47	-7.42	7.99	-7.73	-4	-0.21	-0.15	0.16	0.05	0.36	-0.22	-0.31	-0.1	-0.16	-19.19
55	6.77	1.1	-1.84	2.11	0.37	0.08	0.24	-0.08	0.55	-0.57	-0.27	-0.19	0	-27.99
71	8.05	0.87	-5.67	-0.18	-0.62	-0.25	-0.21	-0.12	-0.85	0.25	0.01	0.12		21.46
78	4.94	-0.97	2.03	0.31	0.07	-0.07	-0.19	-0.15	-0.85	0.3	-0.58	-0.13	-0.42	-19.06
37	-2.87	-2.47	6.93	-1.15	-0.06	-0.11	-0.03	-0.04	0.2	0.24	0	0.1	0.11	13.42
76	-0.24	-3.65	5.94	-0.12	-0.16	0	0.12	0.2	-0.2	0.13	0.05	0.08	0.28	7.94
80	8.99	-0.06	6.43	-0.54	-0.13	-0.06	-0.4	0.03	-0.08	-0.48	-0.35	-0.14	-0.09	-18.55
81	-4.43	-0.76	3.18	1.35	-0.08	-0.16	0.03	-0.15	0.4	0.94	0.19	-0.13	0.4	-19.04
82	4.92	3.74	0.38	2.46	-0.36	0.17	-0.05	-0.01	-1.55	-0.38	-0.06	0.23	0.02	43.86
83	6.22	8.77	0.76	1.67	-0.06	-0.16	0	-0.12	0.12	0.4	0.01	0.07	0.84	16.17

AIM 4 Statistical Output

Vastus Lateralis:

Tests of Within-Subjects Effects

Measure:MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Condition	Sphericity Assumed	1.335	1	1.335	5.827	.021	.130	5.827	.653
	Greenhouse-Geisser	1.335	1.000	1.335	5.827	.021	.130	5.827	.653
	Huynh-Feldt	1.335	1.000	1.335	5.827	.021	.130	5.827	.653
	Lower-bound	1.335	1.000	1.335	5.827	.021	.130	5.827	.653
Condition * Group	Sphericity Assumed	1.144	3	.381	1.665	.190	.114	4.995	.402
	Greenhouse-Geisser	1.144	3.000	.381	1.665	.190	.114	4.995	.402
	Huynh-Feldt	1.144	3.000	.381	1.665	.190	.114	4.995	.402
	Lower-bound	1.144	3.000	.381	1.665	.190	.114	4.995	.402
Error(Condition)	Sphericity Assumed	8.933	39	.229					
	Greenhouse-Geisser	8.933	39.000	.229					
	Huynh-Feldt	8.933	39.000	.229					
	Lower-bound	8.933	39.000	.229					

a. Computed using alpha =

Tests of Between-Subjects Effects

Measure:MEASURE_1
Transformed Variable:Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Intercept	116.483	1	116.483	343.329	.000	.898	343.329	1.000
Group	2.721	3	.907	2.673	.061	.171	8.019	.607
Error	13.232	39	.339					

a. Computed using alpha =

2. Group

Estimates

Measure:MEASURE_1

Group	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1	1.066	.130	.803	1.329
2	.988	.156	.674	1.303
3	1.304	.114	1.073	1.536
4	1.448	.114	1.217	1.679

Pairwise Comparisons

Measure:MEASURE_1

(I) Group	(J) Group	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1	2	.078	.203	1.000	-.487	.642
	3	-.238	.173	1.000	-.720	.243
	4	-.382	.173	.201	-.863	.100
2	1	-.078	.203	1.000	-.642	.487
	3	-.316	.193	.659	-.853	.221
	4	-.459	.193	.134	-.996	.077
3	1	.238	.173	1.000	-.243	.720
	2	.316	.193	.659	-.221	.853
	4	-.143	.162	1.000	-.592	.306
4	1	.382	.173	.201	-.100	.863
	2	.459	.193	.134	-.077	.996
	3	.143	.162	1.000	-.306	.592

Based on estimated marginal means

a. Adjustment for multiple comparisons: Bonferroni.

3. Condition

Estimates

Measure:MEASURE_1

Condition	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1	1.330	.090	1.148	1.513
2	1.073	.077	.917	1.229

Pairwise Comparisons

Measure:MEASURE_1

(I) Condition	(J) Condition	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1	2	.257*	.107	.021	.042	.473
2	1	-.257*	.107	.021	-.473	-.042

Based on estimated marginal means

*. The mean difference is significant at the

a. Adjustment for multiple comparisons: Bonferroni.

Rectus Femoris:

Tests of Within-Subjects Effects

Measure:MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Condition	Sphericity Assumed	.135	1	.135	7.141	.011	.169	7.141	.738
	Greenhouse-Geisser	.135	1.000	.135	7.141	.011	.169	7.141	.738
	Huynh-Feldt	.135	1.000	.135	7.141	.011	.169	7.141	.738
	Lower-bound	.135	1.000	.135	7.141	.011	.169	7.141	.738
Condition * Group	Sphericity Assumed	.146	3	.049	2.568	.070	.180	7.703	.582
	Greenhouse-Geisser	.146	3.000	.049	2.568	.070	.180	7.703	.582
	Huynh-Feldt	.146	3.000	.049	2.568	.070	.180	7.703	.582
	Lower-bound	.146	3.000	.049	2.568	.070	.180	7.703	.582
Error(Condition)	Sphericity Assumed	.663	35	.019					
	Greenhouse-Geisser	.663	35.000	.019					
	Huynh-Feldt	.663	35.000	.019					
	Lower-bound	.663	35.000	.019					

a. Computed using alpha =

Tests of Between-Subjects Effects

Measure:MEASURE_1

Transformed Variable:Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Intercept	11.728	1	11.728	265.455	.000	.884	265.455	1.000
Group	.086	3	.029	.651	.588	.053	1.952	.172
Error	1.546	35	.044					

a. Computed using alpha =

2. Group

Estimates

Measure:MEASURE_1

Group	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1	.450	.047	.355	.545
2	.361	.056	.247	.475
3	.397	.043	.310	.484
4	.373	.047	.278	.468

Pairwise Comparisons

Measure:MEASURE_1

(I) Group	(J) Group	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1	2	.089	.073	1.000	-.115	.294
	3	.053	.064	1.000	-.125	.231
	4	.077	.066	1.000	-.109	.263
2	1	-.089	.073	1.000	-.294	.115
	3	-.037	.071	1.000	-.234	.161
	4	-.012	.073	1.000	-.217	.193
3	1	-.053	.064	1.000	-.231	.125
	2	.037	.071	1.000	-.161	.234
	4	.024	.064	1.000	-.154	.202
4	1	-.077	.066	1.000	-.263	.109
	2	.012	.073	1.000	-.193	.217
	3	-.024	.064	1.000	-.202	.154

Based on estimated marginal means

a. Adjustment for multiple comparisons: Bonferroni.

3. Condition

Estimates

Measure:MEASURE_1

Condition	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1	.438	.033	.371	.504
2	.353	.025	.303	.403

Pairwise Comparisons

Measure:MEASURE_1

(I) Condition	(J) Condition	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1	2	.085*	.032	.011	.020	.149
2	1	-.085*	.032	.011	-.149	-.020

Based on estimated marginal means

*. The mean difference is significant at the

a. Adjustment for multiple comparisons: Bonferroni.

Lateral Hamstrings:

Tests of Within-Subjects Effects

Measure:MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Condition	Sphericity Assumed	.024	1	.024	1.350	.253	.035	1.350	.205
	Greenhouse-Geisser	.024	1.000	.024	1.350	.253	.035	1.350	.205
	Huynh-Feldt	.024	1.000	.024	1.350	.253	.035	1.350	.205
	Lower-bound	.024	1.000	.024	1.350	.253	.035	1.350	.205
Condition * Group	Sphericity Assumed	.165	3	.055	3.108	.038	.201	9.323	.677
	Greenhouse-Geisser	.165	3.000	.055	3.108	.038	.201	9.323	.677
	Huynh-Feldt	.165	3.000	.055	3.108	.038	.201	9.323	.677
	Lower-bound	.165	3.000	.055	3.108	.038	.201	9.323	.677
Error(Condition)	Sphericity Assumed	.655	37	.018					
	Greenhouse-Geisser	.655	37.000	.018					
	Huynh-Feldt	.655	37.000	.018					
	Lower-bound	.655	37.000	.018					

a. Computed using alpha =

Tests of Between-Subjects Effects

Measure:MEASURE_1
Transformed Variable:Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Intercept	10.801	1	10.801	143.840	.000	.795	143.840	1.000
Group	.056	3	.019	.249	.862	.020	.746	.093
Error	2.778	37	.075					

a. Computed using alpha =

2. Group

Estimates

Measure:MEASURE_1

Group	Mean	Std. Error	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
1	.386	.061	.262	.511
2	.326	.073	.178	.475
3	.373	.058	.255	.492
4	.403	.054	.294	.512

Pairwise Comparisons

Measure:MEASURE_1

(I) Group	(J) Group	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a] Lower Bound	95% Confidence Interval for Difference[a] Upper Bound
1	2	.060	.095	1.000	-.206	.326
	3	.013	.085	1.000	-.223	.249
	4	-.017	.082	1.000	-.244	.210
2	1	-.060	.095	1.000	-.326	.206
	3	-.047	.094	1.000	-.309	.214
	4	-.077	.091	1.000	-.330	.176
3	1	-.013	.085	1.000	-.249	.223
	2	.047	.094	1.000	-.214	.309
	4	-.030	.079	1.000	-.251	.192
4	1	.017	.082	1.000	-.210	.244
	2	.077	.091	1.000	-.176	.330
	3	.030	.079	1.000	-.192	.251

Based on estimated marginal means

a. Adjustment for multiple comparisons: Bonferroni.

3. Condition

Estimates

Measure:MEASURE_1

Condition	Mean	Std. Error	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
1	.390	.036	.318	.462
2	.355	.033	.287	.423

Pairwise Comparisons

Measure:MEASURE_1

(I) Condition	(J) Condition	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a] Lower Bound	95% Confidence Interval for Difference[a] Upper Bound
1	2	.035	.030	.253	-.026	.096
2	1	-.035	.030	.253	-.096	.026

Based on estimated marginal means

a. Adjustment for multiple comparisons: Bonferroni.

5. Group * Condition

Estimates

Measure:MEASURE_1

Group	Condition	Mean	Std. Error	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
1	1	.456	.070	.314	.599
	2	.316	.066	.183	.450
2	1	.372	.084	.202	.542
	2	.281	.079	.121	.441
3	1	.325	.067	.190	.461
	2	.422	.063	.294	.549
4	1	.406	.062	.281	.531
	2	.400	.058	.283	.518

Pairwise Comparisons

Measure:MEASURE_1

Group	(I) Condition	(J) Condition	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a] Lower Bound	95% Confidence Interval for Difference[a] Upper Bound
1	1	2	.140*	.060	.024	.019	.261
	2	1	-.140*	.060	.024	-.261	-.019
2	1	2	.091	.071	.209	-.053	.235
	2	1	-.091	.071	.209	-.235	.053
3	1	2	-.097	.057	.097	-.212	.018
	2	1	.097	.057	.097	-.018	.212
4	1	2	.006	.052	.911	-.100	.112
	2	1	-.006	.052	.911	-.112	.100

Based on estimated marginal means

*. The mean difference is significant at the

a. Adjustment for multiple comparisons: Bonferroni.

Gluteus Medius:

Tests of Within-Subjects Effects

Measure:MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Condition	Sphericity Assumed	.000	1	.000	.002	.962	.000	.002	.050
	Greenhouse-Geisser	.000	1.000	.000	.002	.962	.000	.002	.050
	Huynh-Feldt	.000	1.000	.000	.002	.962	.000	.002	.050
	Lower-bound	.000	1.000	.000	.002	.962	.000	.002	.050
Condition * Group	Sphericity Assumed	.524	3	.175	2.417	.082	.164	7.252	.557
	Greenhouse-Geisser	.524	3.000	.175	2.417	.082	.164	7.252	.557
	Huynh-Feldt	.524	3.000	.175	2.417	.082	.164	7.252	.557
	Lower-bound	.524	3.000	.175	2.417	.082	.164	7.252	.557
Error(Condition)	Sphericity Assumed	2.672	37	.072					
	Greenhouse-Geisser	2.672	37.000	.072					
	Huynh-Feldt	2.672	37.000	.072					
	Lower-bound	2.672	37.000	.072					

a. Computed using alpha =

Tests of Between-Subjects Effects

Measure:MEASURE_1

Transformed Variable:Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Intercept	32.757	1	32.757	565.624	.000	.939	565.624	1.000
Group	.291	3	.097	1.675	.189	.120	5.025	.402
Error	2.143	37	.058					

a. Computed using alpha =

2. Group

Estimates

Measure:MEASURE_1

Group	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1	.637	.054	.528	.746
2	.760	.064	.630	.890
3	.601	.049	.502	.701
4	.592	.049	.492	.691

Pairwise Comparisons

Measure:MEASURE_1

(I) Group	(J) Group	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1	2	-.123	.084	.909	-.357	.111
	3	.036	.073	1.000	-.167	.239
	4	.046	.073	1.000	-.158	.249
2	1	.123	.084	.909	-.111	.357
	3	.159	.081	.346	-.067	.384
	4	.168	.081	.267	-.057	.394
3	1	-.036	.073	1.000	-.239	.167
	2	-.159	.081	.346	-.384	.067
	4	.010	.069	1.000	-.184	.203
4	1	-.046	.073	1.000	-.249	.158
	2	-.168	.081	.267	-.394	.057
	3	-.010	.069	1.000	-.203	.184

Based on estimated marginal means

a. Adjustment for multiple comparisons: Bonferroni.

3. Condition

Estimates

Measure:MEASURE_1

Condition	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1	.649	.042	.563	.734
2	.646	.039	.566	.726

Pairwise Comparisons

Measure:MEASURE_1

(I) Condition	(J) Condition	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1	2	.003	.061	.962	-.120	.126
2	1	-.003	.061	.962	-.126	.120

Based on estimated marginal means

a. Adjustment for multiple comparisons: Bonferroni.

VL:LH:

Tests of Within-Subjects Effects

Measure:MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Condition	Sphericity Assumed	314.541	1	314.541	.775	.384	.021	.775	.138
	Greenhouse-Geisser	314.541	1.000	314.541	.775	.384	.021	.775	.138
	Huynh-Feldt	314.541	1.000	314.541	.775	.384	.021	.775	.138
	Lower-bound	314.541	1.000	314.541	.775	.384	.021	.775	.138
Condition * Group	Sphericity Assumed	3372.981	3	1124.327	2.770	.055	.183	8.309	.621
	Greenhouse-Geisser	3372.981	3.000	1124.327	2.770	.055	.183	8.309	.621
	Huynh-Feldt	3372.981	3.000	1124.327	2.770	.055	.183	8.309	.621
	Lower-bound	3372.981	3.000	1124.327	2.770	.055	.183	8.309	.621
Error(Condition)	Sphericity Assumed	15019.883	37	405.943					
	Greenhouse-Geisser	15019.883	37.000	405.943					
	Huynh-Feldt	15019.883	37.000	405.943					
	Lower-bound	15019.883	37.000	405.943					

a. Computed using alpha =

Tests of Between-Subjects Effects

Measure:MEASURE_1
Transformed Variable:Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Intercept	211661.087	1	211661.087	114.307	.000	.755	114.307	1.000
Group	1222.658	3	407.553	.220	.882	.018	.660	.087
Error	68512.226	37	1851.682					

a. Computed using alpha =

2. Group

Estimates

Measure:MEASURE_1

Group	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1	56.844	9.622	37.348	76.340
2	45.805	11.501	22.502	69.107
3	50.833	9.174	32.244	69.422
4	54.997	8.439	37.898	72.096

Pairwise Comparisons

Measure:MEASURE_1

(I) Group	(J) Group	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1	2	11.039	14.995	1.000	-30.761	52.839
	3	6.011	13.295	1.000	-31.049	43.072
	4	1.847	12.799	1.000	-33.830	37.524
2	1	-11.039	14.995	1.000	-52.839	30.761
	3	-5.028	14.712	1.000	-46.038	35.982
	4	-9.192	14.265	1.000	-48.957	30.572
3	1	-6.011	13.295	1.000	-43.072	31.049
	2	5.028	14.712	1.000	-35.982	46.038
	4	-4.164	12.465	1.000	-38.913	30.584
4	1	-1.847	12.799	1.000	-37.524	33.830
	2	9.192	14.265	1.000	-30.572	48.957
	3	4.164	12.465	1.000	-30.584	38.913

Based on estimated marginal means

a. Adjustment for multiple comparisons: Bonferroni.

3. Condition

Estimates

Measure:MEASURE_1

Condition	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1	54.129	5.535	42.915	65.343
2	50.111	5.227	39.521	60.700

Pairwise Comparisons

Measure:MEASURE_1

(I) Condition	(J) Condition	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1	2	4.018	4.565	.384	-5.231	13.268
2	1	-4.018	4.565	.384	-13.268	5.231

Based on estimated marginal means

a. Adjustment for multiple comparisons: Bonferroni.

Peak Rotations:

Variables Entered/Removed[a]

Model	Variables Entered	Variables Removed	Method
1	VL	.	Stepwise (Criteria: Probability-of-F-to-enter <= .050, Probability-of-F-to-remove >= .100).

a. Dependent Variable: KneeAbd

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.322[a]	.104	.081	2.56454

a. Predictors: (Constant), VL

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	29.692	1	29.692	4.515	.040[a]
	Residual	256.498	39	6.577		
	Total	286.190	40			

a. Predictors: (Constant), VL

b. Dependent Variable: KneeAbd

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	.036	.437		.083	.935
	VL	1.226	.577	.322	2.125	.040

a. Dependent Variable: KneeAbd

Excluded Variables[b]

Model		Beta In	t	Sig.	Partial Correlation	Collinearity Statistics
						Tolerance
1	LH	.029[a]	.188	.852	.030	.994
	LatQH	.045[a]	.293	.771	.047	.994

a. Predictors in the Model: (Constant), VL

b. Dependent Variable: KneeAbd

CORE:

Variables Entered/Removed[a]

Model	Variables Entered	Variables Removed	Method
1	LatQH	.	Stepwise (Criteria: Probability-of-F-to-enter <= .050, Probability-of-F-to-remove >= .100).

a. Dependent Variable: KneeAbd

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.828[a]	.685	.622	2.22566

a. Predictors: (Constant), LatQH

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	53.844	1	53.844	10.870	.022[a]
	Residual	24.768	5	4.954		
	Total	78.612	6			

a. Predictors: (Constant), LatQH
b. Dependent Variable: KneeAbd

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-1.414	.909		-1.555	.181
	LatQH	-.091	.027	-.828	-3.297	.022

a. Dependent Variable: KneeAbd

Excluded Variables[b]

Model		Beta In	t	Sig.	Partial Correlation	Collinearity Statistics
						Tolerance
1	VL	.262[a]	.986	.380	.442	.900
	LH	1.170[a]	1.035	.359	.460	.049

a. Predictors in the Model: (Constant), LatQH
b. Dependent Variable: KneeAbd

CON:

Variables Entered/Removed[a]

Model	Variables Entered	Variables Removed	Method
1	VL	.	Stepwise (Criteria: Probability-of-F-to-enter <= .050, Probability-of-F-to-remove >= .100).

a. Dependent Variable: KneeAbd

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.713[a]	.508	.464	1.54808

a. Predictors: (Constant), VL

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	27.250	1	27.250	11.371	.006[a]
	Residual	26.362	11	2.397		
	Total	53.613	12			

a. Predictors: (Constant), VL
b. Dependent Variable: KneeAbd

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-.067	.517		-.129	.900
	VL	1.540	.457	.713	3.372	.006

a. Dependent Variable: KneeAbd

Excluded Variables[b]

Model		Beta In	t	Sig.	Partial Correlation	Collinearity Statistics
						Tolerance
1	LH	.132[a]	.607	.557	.188	.998
	LatQH	.135[a]	.608	.557	.189	.966

a. Predictors in the Model: (Constant), VL
b. Dependent Variable: KneeAbd

Variables Entered/Removed[a]

Model	Variables Entered	Variables Removed	Method
1	LH	.	Stepwise (Criteria: Probability-of-F-to-enter <= .050, Probability-of-F-to-remove >= .100).

a. Dependent Variable: HipFlxTrq

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.505[a]	.255	.232	.19081

a. Predictors: (Constant), LH

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	.411	1	.411	11.278	.002[a]
	Residual	1.202	33	.036		
	Total	1.612	34			

a. Predictors: (Constant), LH

b. Dependent Variable: HipFlxTrq

Coefficients[a]

		Unstandardized Coefficients		Standardized Coefficients		
Model		B	Std. Error	Beta	t	Sig.
1	(Constant)	-.001	.033		-.034	.973
	LH	-.509	.152	-.505	-3.358	.002

a. Dependent Variable: HipFlxTrq

Excluded Variables[b]

						Collinearity Statistics
Model		Beta In	t	Sig.	Partial Correlation	Tolerance
1	RF	-.280[a]	-1.800	.081	-.303	.873
	GM	.127[a]	.755	.456	.132	.802

a. Predictors in the Model: (Constant), LH

b. Dependent Variable: HipFlxTrq

Peak Moments

Variables Entered/Removed[a]

Model	Variables Entered	Variables Removed	Method
1	LH	.	Stepwise (Criteria: Probability-of-F-to-enter <= .050, Probability-of-F-to-remove >= .100).

a. Dependent Variable: HipFlxTrq

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.505[a]	.255	.232	.19081

a. Predictors: (Constant), LH

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	.411	1	.411	11.278	.002[a]
	Residual	1.202	33	.036		
	Total	1.612	34			

a. Predictors: (Constant), LH
b. Dependent Variable: HipFlxTrq

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-.001	.033		-.034	.973
	LH	-.509	.152	-.505	-3.358	.002

a. Dependent Variable: HipFlxTrq

Excluded Variables[b]

Model		Beta In	t	Sig.	Partial Correlation	Collinearity Statistics
						Tolerance
1	RF	-.280[a]	-1.800	.081	-.303	.873
	GM	.127[a]	.755	.456	.132	.802

a. Predictors in the Model: (Constant), LH
b. Dependent Variable: HipFlxTrq

Variables Entered/Removed[a]

Model	Variables Entered	Variables Removed	Method
1	LH	.	Stepwise (Criteria: Probability-of-F-to-enter <= .050, Probability-of-F-to-remove >= .100).

a. Dependent Variable: KneeFlxTrq

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.311[a]	.096	.073	.22057

a. Predictors: (Constant), LH

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	.202	1	.202	4.162	.048[a]
	Residual	1.897	39	.049		
	Total	2.100	40			

a. Predictors: (Constant), LH

b. Dependent Variable: KneeFlxTrq

Coefficients[a]

		Unstandardized Coefficients		Standardized Coefficients		
Model		B	Std. Error	Beta	t	Sig.
1	(Constant)	.014	.035		.396	.694
	LH	-.351	.172	-.311	-2.040	.048

a. Dependent Variable: KneeFlxTrq

Excluded Variables[b]

						Collinearity Statistics
Model		Beta In	t	Sig.	Partial Correlation	Tolerance
1	VL	-.025[a]	-.160	.874	-.026	.994
	LatQH	.212[a]	.285	.778	.046	.043

a. Predictors in the Model: (Constant), LH

b. Dependent Variable: KneeFlxTrq

Variables Entered/Removed[a]

Model	Variables Entered	Variables Removed	Method
1	RF	.	Stepwise (Criteria: Probability-of-F-to-enter <= .050, Probability-of-F-to-remove >= .100).

a. Dependent Variable: AntShr

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.424[a]	.180	.156	.67428

a. Predictors: (Constant), RF

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	3.486	1	3.486	7.668	.009[a]
	Residual	15.913	35	.455		
	Total	19.399	36			

a. Predictors: (Constant), RF
b. Dependent Variable: AntShr

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	.168	.122		1.373	.179
	RF	1.613	.582	.424	2.769	.009

a. Dependent Variable: AntShr

Excluded Variables[b]

Model		Beta In	t	Sig.	Partial Correlation	Collinearity Statistics
						Tolerance
1	VL	-.143[a]	-.876	.387	-.149	.889
	LH	-.021[a]	-.126	.900	-.022	.859

a. Predictors in the Model: (Constant), RF
b. Dependent Variable: AntShr

NM:

Variables Entered/Removed[a]

Model	Variables Entered	Variables Removed	Method
1	LH	.	Stepwise (Criteria: Probability-of-F-to-enter <= .050, Probability-of-F-to-remove >= .100).

a. Dependent Variable: HipFlxTrq

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.696[a]	.484	.420	.18830

a. Predictors: (Constant), LH

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	.267	1	.267	7.517	.025[a]
	Residual	.284	8	.035		
	Total	.550	9			

a. Predictors: (Constant), LH
b. Dependent Variable: HipFlxTrq

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-.030	.071		-.425	.682
	LH	-.742	.271	-.696	-2.742	.025

a. Dependent Variable: HipFlxTrq

Excluded Variables[b]

Model		Beta In	t	Sig.	Partial Correlation	Collinearity Statistics
						Tolerance
1	RF	-.137[a]	-.431	.679	-.161	.713
	GM	-.146[a]	-.522	.618	-.193	.909

a. Predictors in the Model: (Constant), LH
b. Dependent Variable: HipFlxTrq

Variables Entered/Removed[a]

Model	Variables Entered	Variables Removed	Method
1	LH	.	Stepwise (Criteria: Probability-of-F-to-enter <= .050, Probability-of-F-to-remove >= .100).

a. Dependent Variable: AntShr

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.785[a]	.616	.568	.54659

a. Predictors: (Constant), LH

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	3.832	1	3.832	12.827	.007[a]
	Residual	2.390	8	.299		
	Total	6.222	9			

a. Predictors: (Constant), LH
b. Dependent Variable: AntShr

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	.720	.205		3.513	.008
	LH	2.814	.786	.785	3.582	.007

a. Dependent Variable: AntShr

Excluded Variables[b]

Model		Beta In	t	Sig.	Partial Correlation	Collinearity Statistics
						Tolerance
1	VL	.051[a]	.217	.834	.082	1.000
	RF	.356[a]	1.464	.186	.484	.713

a. Predictors in the Model: (Constant), LH
b. Dependent Variable: AntShr

PLYO:

Variables Entered/Removed[a]

Model	Variables Entered	Variables Removed	Method
1	RF	.	Stepwise (Criteria: Probability-of-F-to-enter <= .050, Probability-of-F-to-remove >= .100).

a. Dependent Variable: HipFlxTrq

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.669[a]	.447	.368	.18810

a. Predictors: (Constant), RF

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	.201	1	.201	5.667	.049[a]
	Residual	.248	7	.035		
	Total	.448	8			

a. Predictors: (Constant), RF
b. Dependent Variable: HipFlxTrq

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-.012	.063		-.189	.856
	RF	-1.246	.524	-.669	-2.381	.049

a. Dependent Variable: HipFlxTrq

Excluded Variables[b]

Model		Beta In	t	Sig.	Partial Correlation	Collinearity Statistics
						Tolerance
1	LH	-.287[a]	-.941	.383	-.359	.861
	GM	-.258[a]	-.904	.401	-.346	.992

a. Predictors in the Model: (Constant), RF
b. Dependent Variable: HipFlxTrq

Table E.14. Pre- and Post-Training Hip and Knee Strength Data

	Pre-Training						Post-Training					
	Knee		Hip		Hip		Knee		Hip		Hip	
SubjID	**Ext**	**Flx**	**Ext**	**Flx**	**Abd**	**Add**	**Ext**	**Flx**	**Ext**	**Flx**	**Abd**	**Add**
1	1.08	0.93	1.04	1.19	0.86	1.03	1.77	0.91	1.01	1.29	0.91	0.71
8	1.24	1.16	1.25	1.22	0.42	0.81	1.58	1.17	0.89	0.95	0.62	0.90
16	1.26	0.71	0.95	0.98	0.42	0.76	0.90	0.77	1.02	0.86	0.56	0.78
34	1.70	0.84	0.89	0.70	0.44	0.81	2.16	0.98	1.14	1.01	0.47	0.92
35	2.05	1.18	1.41	1.15	0.83	0.96	2.05	1.63	1.92	1.62	0.81	0.89
36	1.61	1.09	1.63	1.00	0.81	1.21	1.62	1.19	2.31	1.10	0.62	1.07
38	1.84	0.95	1.15	1.28	0.68	1.01	2.11	1.46	1.74	1.42	0.61	1.00
39	1.58	1.17	1.24	1.16	0.74	1.12	2.19	1.48	1.56	1.42	0.67	1.16
40	0.92	0.82	1.20	1.30	0.72	0.83	1.90	0.97	1.36	1.25	0.71	0.98
41	1.44	0.83	0.90	0.93	0.68	1.01	1.52	1.14	1.39	1.12	0.86	1.03
43	1.36	1.04	1.15	0.80	0.24	0.41	1.11	0.89	1.46	1.05	0.77	1.01
44	1.01	0.96	1.66	1.03	0.68	1.11	1.65	1.16	1.57	1.13	0.61	1.03
49	1.74	1.14	1.31	0.75	0.48	1.14	1.78	1.15	1.71	1.12	0.57	1.13
50	0.99	0.75	1.01	0.76	0.29	0.46	1.17	0.77	0.90	0.81	0.50	0.61
51	0.95	0.83	1.42	0.73	0.75	1.32	1.17	0.93	1.57	1.05	0.48	0.90
52	1.61	1.44	1.70	1.28	0.96	0.93	1.80	1.08	1.44	1.18	0.96	0.96
53	2.03	1.24	1.47	1.10	0.53	1.08	1.69	1.15	1.32	1.20	0.59	1.07
54	2.60	1.37	1.46	0.96	0.66	1.11	2.43	1.25	1.35	0.86	0.90	0.99
59	1.78	1.33	1.28	1.36	0.60	1.09	1.78	1.52	1.08	1.22	0.57	0.77
60	1.48	1.10	1.34	1.12	0.54	0.98	1.99	1.16	1.50	1.38	0.66	1.00
61	2.00	1.30	1.17	1.05	0.60	0.82	1.88	1.09	1.29	1.11	0.58	0.90
62	1.44	1.14	1.25	0.97	0.55	0.95	1.55	1.01	1.41	1.32	0.60	0.71
63	2.12	1.12	1.05	1.21	0.37	0.77	2.17	1.16	1.11	1.12	0.53	0.66
64	1.80	1.25	1.09	0.97	0.53	0.65	2.18	1.40	1.05	0.93	0.49	0.88

Table E.14. cont'd

	Pre-Training						Post-Training					
	Knee		Hip		Hip		Knee		Hip		Hip	
SubjID	**Ext**	**Flx**	**Ext**	**Flx**	**Abd**	**Add**	**Ext**	**Flx**	**Ext**	**Flx**	**Abd**	**Add**
64	1.80	1.25	1.09	0.97	0.53	0.65	2.18	1.40	1.05	0.93	0.49	0.88
65	1.73	1.08	1.57	1.26	0.66	0.74	1.39	1.13	1.39	0.95	0.55	0.90
67	1.92	1.12	1.52	1.00	0.62	0.70	1.90	1.24	2.23	1.56	0.50	0.80
68	1.57	0.98	1.15	0.64	0.30	0.79	1.35	1.16	1.04	1.15	0.34	0.87
74	1.92	1.19	1.06	1.08	0.33	0.97	2.33	1.28	1.28	1.25	0.51	0.92
7	1.14	1.15	0.87	1.08	0.33	1.03	1.51	0.89	1.10	1.27	0.41	0.66
12	1.60	0.82	1.22	1.05	0.64	1.10	1.73	1.29	2.16	1.26	0.53	1.20
14	1.76	1.03	1.52	1.13	0.73	1.14	1.98	0.98	1.60	1.26	0.70	1.00
15	1.84	0.84	1.40	1.08	0.69	0.90	1.86	1.12	1.20	1.20	0.72	0.80
45	2.24	1.03	1.53	1.47	0.82	1.10	2.05	1.40	1.76	1.58	0.96	1.08
46	1.22	0.99	1.10	0.95	0.47	0.94	1.29	0.96	1.06	1.17	0.30	0.69
47	1.34	1.08	1.43	1.01	0.65	1.37	2.18	1.36	1.69	1.31	0.73	0.87
55	1.90	1.34	1.33	1.01	0.80	0.92	2.26	1.55	1.72	1.27	0.96	1.05
71	1.99	1.39	1.95	1.18	0.32	1.18	1.98	1.45	1.95	1.50	0.79	1.15
78	1.36	1.18	1.20	0.84	0.52	1.06	1.86	1.33	1.47	1.39	0.83	0.99
37	2.13	1.02	1.34	1.06	0.90	1.01	3.15	1.55	1.01	1.20	1.00	0.81
76	1.46	1.17	0.94	0.68	0.39	0.65	1.23	0.97	0.90	1.13	0.45	0.56
80	1.48	1.14	1.34	1.21	0.52	1.04	1.39	1.15	1.40	1.19	0.59	0.70
81	1.53	1.26	1.12	1.19	0.61	0.92	2.13	1.36	1.80	1.60	0.65	1.07
82	1.98	1.32	1.31	1.05	0.45	0.66	1.28	0.85	1.34	0.97	0.60	0.93
83	2.36	1.33	1.12	1.20	0.75	0.81	2.07	1.31	1.46	1.38	0.83	0.77

Table E.15. Pre- and Post-Training Vertical Jump Height Data

Subj ID	Training Group	CMJ (m)		Vertical (m)	
		Pre	Post	Pre	Post
1	4	0.29	0.31	0.31	0.30
7	4	0.29	0.22	0.25	0.22
8	4	0.16	0.18	0.16	0.14
12	4	0.23	0.26	1.27	0.29
14	4	0.27	0.25	0.24	0.22
15	4	0.23	0.23	0.16	0.18
16	4	0.23	0.24	0.19	0.23
34	3	0.32	0.35	0.34	0.34
35	2	0.26	0.27	0.24	0.25
36	2	0.23	0.23	0.25	0.23
37	2	0.37	0.34	0.29	0.29
38	1	0.26	0.25	0.24	0.25
39	1	0.27	0.24	0.21	0.24
40	1	0.25	0.28	0.18	0.24
41	1	0.22	0.23	1.91	0.26
43	1	0.23	0.25	0.21	0.25
45	2	0.25	0.29	0.15	0.25
46	1	0.27	0.25	0.26	0.25
47	1	0.27	0.22	0.16	0.20
49	1	0.29	0.26	0.20	0.26
50	3	0.23	0.24	0.25	0.25
51	1	0.26	0.29	0.27	0.27
52	1	0.22	0.23	0.20	0.20
53	3	0.31	0.29	0.08	0.21
54	4	0.24	0.23	0.26	0.25
55	3	0.30	0.28	0.16	0.26
59	2	0.33	0.35	0.33	0.35
60	3	0.32	0.31	0.29	0.30
61	3	0.28	0.29	0.26	0.28
62	3	0.32	0.34	0.29	0.32
63	3	0.26	0.27	0.30	0.29
64	3	0.24	0.25	0.25	0.26
65	3	0.24	0.24	0.13	0.21
67	3	0.24	0.24	0.21	0.25
68	3	0.26	0.28	0.21	0.23
71	2	0.25	0.26	0.20	0.23
74	3	0.25	0.23	0.21	0.19

Table E.15. cont'd

Subj ID	Training Group	CMJ (m)		Vertical (m)	
		Pre	Post	Pre	Post
76	2	0.20	0.22	0.19	0.21
78	4	0.22	0.24	0.23	0.23
80	4	0.25	0.26	0.26	0.27
81	4	0.32	0.30	0.31	0.31
82	4	0.23	0.22	0.24	0.22
83	4	0.28	0.28	0.29	0.28

Table E.16. Pre- and Post-Training Static Balance Data

Subj ID	Train Group	Pre-Training								Post-Training							
		Open			Closed					Open				Closed			
		COP AP	COP ML	Speed	COP AP	COP ML	Speed	Sway	Sway	COP AP	COP ML	Speed	Sway	COP AP	COP ML	Speed	Sway
1	4	27.29	21.35	23.01	0.46	105.96	76.29	119.63	2.40	40.93	71.87	36.04	0.72	76.14	63.00	90.98	1.82
7	4	152.49	125.98	85.21	1.71	105.00	144.99	111.30	2.23	34.55	40.80	45.08	0.90	101.07	136.83	121.82	2.43
8	4	54.30	34.49	41.91	0.84	103.84	60.29	100.52	2.01	55.30	32.47	41.96	0.84	242.24	208.19	166.95	3.31
12	4	61.61	64.03	50.45	1.01	166.84	167.36	119.85	2.40	78.37	131.74	48.81	0.98	149.08	251.61	124.44	2.49
14	4	47.57	28.06	33.10	0.66	77.28	52.84	68.75	1.38	40.53	28.91	30.63	0.61	71.37	43.27	56.12	1.12
15	4	50.41	47.05	38.78	0.78	88.73	57.65	83.47	1.67	41.76	30.30	25.41	0.51	66.21	51.73	59.19	1.18
16	4	49.63	35.93	40.62	0.81	218.78	199.63	169.66	3.40	48.69	31.45	43.01	0.86	156.85	108.36	153.42	3.07
34	3	53.27	30.62	37.32	0.75	103.52	55.91	80.15	1.60	45.53	27.57	36.75	0.74	57.47	47.13	64.93	1.30
35	2	47.04	26.88	49.03	0.98	108.95	95.27	127.23	2.55	33.90	30.27	39.41	0.79	58.24	47.66	95.66	1.92
36	2	51.36	44.46	49.96	1.00	84.64	60.33	109.80	2.20	48.22	45.29	42.48	0.85	74.11	54.86	98.53	1.97
37	2	41.21	37.26	46.93	0.94	58.62	41.33	63.90	1.28	41.97	33.11	35.49	0.71	56.21	47.81	75.91	1.52
38	1	56.02	87.84	67.46	1.35	155.04	126.47	112.16	2.25	62.73	40.43	53.58	1.07	88.54	52.27	85.60	1.71
39	1	34.22	37.10	44.33	0.89	108.09	145.28	89.93	1.80	32.42	31.14	32.82	0.66	45.19	44.28	64.87	1.30
40	1	65.11	42.01	43.77	0.88	157.94	177.64	152.17	3.05	53.49	35.50	49.54	0.99	94.54	58.00	118.09	2.36
41	1	43.79	26.74	34.92	0.70	107.12	144.63	98.81	1.98	38.85	28.19	30.30	0.61	119.82	82.85	116.13	2.32
43	1	84.22	47.57	56.43	1.13	159.41	121.57	143.07	2.86	57.07	35.46	54.86	1.10	115.88	66.44	123.11	2.46
45	2	32.61	25.86	43.93	0.88	82.78	145.12	99.01	1.98	58.24	71.89	41.57	0.83	83.60	51.90	81.20	1.63
46	1	35.49	27.85	41.74	0.84	131.45	151.99	103.42	2.07	39.58	27.60	41.53	0.83	73.55	46.73	84.36	1.69
47	1	35.20	38.52	29.44	0.59	150.95	185.81	102.07	1.97	32.55	27.33	24.08	0.48	77.27	50.88	67.74	1.36
49	1	49.90	61.55	56.37	1.13	99.93	158.90	128.45	2.57	42.00	28.22	38.55	0.77	104.02	51.40	112.61	2.25
50	3	52.56	37.57	51.85	1.04	152.06	116.18	175.63	3.50	49.21	37.47	45.23	0.91	126.62	79.38	104.26	2.09
51	1	110.35	45.67	88.52	1.77	152.59	89.12	185.25	3.71	52.53	31.71	56.69	1.13	134.40	70.23	137.39	2.75
52	1	46.97	31.83	38.40	0.77	184.46	199.56	147.08	2.94	59.11	39.14	44.62	0.89	32.95	18.61	30.74	0.62
53	3	36.74	55.69	46.29	0.93	48.52	70.62	56.70	1.14	37.46	31.35	45.61	0.91	113.93	49.35	95.58	1.91

Table E.16. Cont'd

Subj ID	Train Group	Pre-Training								Post-Training							
		Open				Closed				Open				Closed			
		COP AP	COP ML	Speed	Sway	COP AP	COP ML	Speed	Sway	COP AP	COP ML	Speed	Sway	COP AP	COP ML	Speed	Sway
54	4	57.07	28.69	46.81	0.94	112.82	51.58	90.97	1.82	47.11	34.72	42.41	0.85	57.32	45.16	73.87	1.48
55	3	41.35	31.97	46.64	0.93	78.54	123.45	99.16	1.99	42.58	32.34	43.06	0.86	78.08	48.60	85.48	1.71
59	2	55.62	35.84	38.29	0.77	185.47	111.28	138.01	2.76	40.50	25.98	30.58	0.61	90.10	48.29	76.49	1.53
60	3	56.73	31.55	35.59	0.71	32.94	51.21	56.79	1.14	45.62	47.53	30.34	0.61	56.09	44.69	57.99	1.16
61	3	122.16	48.47	52.64	1.05	139.98	63.14	130.70	2.62	53.53	34.74	46.72	0.94	124.67	77.96	116.55	2.33
62	3	31.27	23.71	29.77	0.60	63.78	74.47	69.30	1.39	30.16	26.22	25.06	0.50	53.48	46.00	59.39	1.19
63	3	42.01	35.62	46.31	0.93	92.54	49.46	93.34	1.87	46.52	30.18	42.51	0.85	64.50	49.07	95.55	1.91
64	3	26.68	19.22	29.10	0.58	147.56	171.61	156.17	3.11	36.72	35.99	41.49	0.83	112.49	57.62	158.39	3.17
65	3	52.37	188.94	72.61	1.45	152.83	110.20	141.19	2.82	38.34	37.70	49.74	1.00	94.15	55.96	100.06	2.00
67	3	60.89	34.74	44.92	0.90	149.15	156.48	192.34	3.85	72.85	38.05	42.30	0.85	84.73	45.36	72.85	1.46
68	3	49.24	61.85	37.50	0.75	83.62	50.60	87.55	1.75	43.58	30.99	33.76	0.68	81.84	50.59	77.56	1.55
71	2	95.90	54.84	51.46	1.03	119.73	83.53	101.34	2.03	52.82	32.29	42.22	0.85	72.69	45.88	65.31	1.31
74	3	39.81	25.24	26.65	0.53	57.46	49.73	63.06	1.26	53.50	29.41	31.50	0.63	68.43	56.40	77.69	1.56
76	2	46.86	40.02	48.31	0.97	114.87	133.16	133.14	2.67	56.78	36.68	62.82	1.26	126.13	63.88	156.44	3.13
78	4	56.34	99.73	45.90	61.04	99.73	45.90	61.04	47.41	45.33	98.61	33.20	80.07	98.61	33.20	80.07	34.36
80	4	26.93	26.96	26.98	0.54	88.69	53.85	74.23	1.49	45.15	36.34	43.64	0.87	72.23	54.69	94.41	1.89
81	4	43.73	40.57	43.99	0.88	68.96	43.25	86.16	1.72	30.26	27.01	26.51	0.53	64.21	46.62	66.93	1.34
82	4	37.27	31.46	27.45	0.55	78.16	51.25	66.97	1.34	35.70	29.45	36.50	0.73	60.52	44.72	80.26	1.61
83	4	39.99	31.61	37.66	0.75	83.77	49.32	86.29	1.73	37.89	24.11	28.14	0.56	154.82	146.05	107.33	1.90

Table E.17. Pre- and Post-Training Dynamic Balance Data

Subj ID	**Train Group**	**Pre-Training**								**Post-Training**							
		Forward				**Medial**				**Forward**				**Medial**			
		APSI	**DPSI**	**MLSI**	**VSI**	**APSI**	**DPSI**	**MLSI**	**VSI**	**APSI**	**DPSI**	**MLSI**	**VSI**	**APSI**	**DPSI**	**MLSI**	**VSI**
1	4	96.18	664.05	16.64	656.82	14.71	331.91	40.63	329.09	93.47	685.05	18.58	678.37	31.55	690.76	59.31	687.38
7	4	86.88	691.95	25.39	686.00	40.72	686.54	66.37	682.11	94.03	686.39	24.08	679.48	40.80	694.82	66.34	690.44
8	4	79.40	652.18	16.61	647.12	31.14	673.20	70.72	668.43	89.46	659.87	16.34	653.56	36.93	652.44	65.58	648.08
12	4	87.52	680.45	20.66	674.47	36.39	666.44	64.88	662.27	88.64	671.67	12.84	665.67	30.02	674.53	71.76	670.00
14	4	97.92	665.52	18.93	657.99	27.58	659.59	58.53	656.39	93.57	668.69	14.24	661.95	33.55	667.75	67.96	663.36
15	4	86.02	662.45	22.74	656.44	46.58	662.96	67.58	657.77	97.18	675.48	25.35	667.96	38.81	674.79	71.27	669.87
16	4	87.08	664.38	19.00	658.34	33.45	652.61	63.12	648.65	89.50	631.09	16.75	624.47	40.10	642.27	66.84	637.52
34	3	84.72	653.62	22.45	647.71	29.30	643.58	62.69	639.85	91.03	651.66	15.81	645.07	24.81	642.87	62.76	639.26
35	2	87.83	651.70	21.02	645.40	34.77	657.03	60.70	653.29	92.49	686.06	20.15	679.49	31.25	676.40	70.48	671.97
36	2	98.52	645.15	21.74	637.20	32.36	639.97	65.28	635.78	91.58	649.10	18.09	642.34	39.05	643.84	65.47	639.24
37	2	94.02	663.34	18.20	656.36	23.62	650.01	66.60	646.15	104.57	646.88	19.42	638.06	16.42	319.49	31.20	317.54
38	1	96.03	671.43	15.96	664.33	40.14	665.21	78.15	659.38	101.49	693.65	23.29	685.75	37.00	678.30	68.65	673.78
39	1	98.13	675.29	19.97	667.75	30.82	668.51	65.19	664.61	92.50	683.57	15.21	677.07	31.68	684.71	72.27	680.14
40	1	88.86	653.61	19.33	647.24	26.80	656.21	58.91	652.96	97.66	653.70	21.51	645.99	29.03	653.83	61.77	650.23
41	1	96.55	677.20	18.25	670.03	35.46	681.32	76.31	676.11	94.61	669.25	15.18	662.31	17.39	664.30	63.40	661.03
43	1	99.89	607.42	23.44	598.59	35.95	695.61	60.84	692.00	94.62	677.27	17.36	670.40	36.44	673.74	65.73	669.48
45	2	104.19	676.90	15.50	668.65	35.95	663.57	68.05	659.09	92.55	695.25	21.91	688.71	34.24	695.41	73.35	690.67
46	1	97.13	697.69	20.91	690.54	35.41	677.40	71.12	672.73	95.31	688.07	17.40	681.19	38.23	680.25	70.87	675.45
47	1	89.08	673.99	14.53	667.91	24.97	666.04	64.53	662.43	88.50	688.46	14.13	682.60	20.36	679.30	60.48	676.29
49	1	87.28	659.72	23.28	653.49	29.22	657.47	69.14	653.17	93.47	671.67	19.54	664.82	31.69	668.22	71.63	663.57
50	3	86.59	681.04	24.36	675.06	38.92	677.27	60.75	673.39	89.61	681.07	21.01	674.82	22.40	340.92	30.71	338.79
51	1	93.80	653.83	21.91	646.68	32.55	658.76	71.48	654.04	98.53	645.78	17.51	637.96	34.89	648.13	67.80	643.61
52	1	82.47	644.64	19.47	639.04	35.99	647.59	66.18	643.19	95.84	686.77	19.85	679.73	32.80	691.86	70.69	687.45
53	3	106.99	671.17	28.90	661.94	34.72	680.18	69.46	675.71	95.36	704.48	16.05	697.76	28.28	701.65	76.63	696.87

Table E.17. cont'd

Subj ID	Train Group	Pre-Training								Post-Training							
		Forward				Medial				Forward				Medial			
		APSI	DPSI	MLSI	VSI	APSI	DPSI	MLSI	VSI	APSI	DPSI	MLSI	VSI	APSI	DPSI	MLSI	VSI
54	4	85.12	666.19	16.59	660.52	38.53	661.43	70.47	656.52	94.25	639.47	21.10	632.11	17.09	316.71	37.95	313.96
55	3	105.97	682.67	20.79	674.07	18.17	329.70	31.32	327.71	105.29	682.97	22.52	674.41	32.96	677.84	68.07	673.59
59	2	84.48	684.73	22.69	679.06	20.12	351.06	38.54	348.35	87.24	693.76	24.75	687.76	33.61	686.09	73.46	681.29
60	3	79.79	666.38	18.03	661.30	16.85	334.94	29.56	333.21	87.50	663.09	16.50	657.08	25.38	656.80	62.73	653.30
61	3	86.91	659.71	18.33	653.69	18.29	332.19	32.99	330.04	84.21	667.96	20.03	662.31	26.54	660.70	61.07	657.32
62	3	92.30	654.63	20.41	647.76	10.35	329.61	28.70	328.20	94.81	658.91	16.97	651.82	22.00	653.43	64.29	649.88
63	3	88.24	655.16	14.79	649.02	10.41	325.70	33.13	323.84	86.18	651.45	13.56	645.55	28.53	652.35	73.32	647.59
64	3	86.99	641.83	18.24	635.64	11.97	323.52	34.36	321.47	93.26	681.53	17.70	674.87	19.72	669.34	66.25	665.76
65	3	80.28	654.83	18.44	649.59	13.46	328.81	35.66	326.59	84.81	667.30	18.70	661.61	22.42	665.80	69.69	661.73
67	3	93.31	672.70	19.12	665.91	36.90	669.58	60.32	665.79	104.83	683.13	19.42	674.72	27.51	678.28	67.31	674.36
68	3	104.62	659.27	20.43	650.58	31.19	651.29	67.99	646.98	92.50	649.52	16.24	642.64	29.23	652.56	73.57	647.72
71	2	94.74	645.24	16.44	638.01	13.43	320.95	29.17	319.34	90.79	660.74	13.80	654.31	29.41	664.74	64.48	660.88
74	3	92.12	689.61	31.60	682.69	14.77	333.99	29.35	332.37	100.59	705.76	22.96	698.17	38.08	711.10	70.02	706.59
76	2	95.37	683.85	19.88	676.85	40.34	692.69	79.84	686.88	101.01	693.25	28.24	685.25	41.20	700.42	89.16	693.47
78	4	84.14	30.92	661.09	657.39	30.92	661.09	657.39	13.84	88.77	23.05	667.64	655.06	23.05	667.64	655.06	16.95
80	4	84.63	644.87	17.74	639.04	14.75	315.30	31.58	313.37	92.55	644.37	23.51	637.24	30.70	635.49	71.20	630.70
81	4	87.76	667.10	15.67	661.09	15.54	329.72	31.42	327.85	87.12	682.64	15.24	676.87	32.46	681.88	64.26	678.06
82	4	92.35	659.73	23.17	652.82	14.33	330.50	35.68	328.26	91.85	668.42	20.86	661.73	33.59	673.72	73.20	668.87
83	4	87.61	660.21	14.87	654.15	15.27	332.29	40.62	329.44	79.75	657.09	16.67	652.02	25.36	662.42	70.80	658.12

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