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ORIGINAL RESEARCH

THE INFLUENCE OF ATTENTIONAL FOCUS ON LANDING STIFFNESS IN FEMALE ATHLETES: A CROSS-SECTIONAL STUDY

Thomas Gus Almonroeder, DPT, PhD[1]
Jithmie Jayawickrema, DPT[2]
Carlee Tonia Richardson, DPT[2]
Kristin Leigh Mercker, DPT, ATC[2]

ABSTRACT

Background: Anterior cruciate ligament injury prevention often involves instructing athletes to reduce landing stiffness. Instructions promoting an external focus appear to result in superior motor performance for a wide range of tasks; however, the effect of attentional focus on landing stiffness has not been examined.

Hypothesis/Purpose: The purpose of this study was to compare the influence of instructions promoting an internal focus vs. those promoting an external focus on landing stiffness. It was hypothesized that both types of instructions would reduce landing stiffness vs. landings performed prior to instruction. It was also hypothesized that participants would demonstrate a greater reduction in landing stiffness when provided with instructions promoting an external focus.

Study Design: Cross-sectional, quasi-experimental

Methods: Sixteen female athletes (basketball, soccer, volleyball) completed drop landings while force and kinematic data were collected. Participants first performed drop landings with their typical technique (baseline). They then received instructions promoting an internal focus and an external focus before performing additional drop landings. Peak force, time-to-peak force, leg stiffness, and hip, knee, and ankle sagittal plane angles were analyzed.

Results: Both types of instructions resulted in lower landing forces, less leg stiffness, and greater hip and knee flexion versus at baseline. However, athletes demonstrated more knee flexion at the time of the peak force ($59.4 \pm 9.6^{\circ}$ vs. $56.0 \pm 9.5^{\circ}$) and less leg stiffness (69.5 ± 17.9 Nkg^{-1}/m vs. 84.0 ± 38.1 Nkg^{-1}/m) when provided with instructions promoting an external focus, compared to when they were provided with instructions promoting an internal focus.

Conclusion: Instructions promoting an external focus appear to result in a greater reduction in landing stiffness. Clinicians should consider providing instructions promoting an external focus when training athletes to reduce lower extremity stiffness during drop landings. The findings from this study may help to inform clinicians involved in movement pattern re-training for female athletes.

Level of Evidence: Level 3b

Keywords: ACL injury, biomechanics, external focus, motor control, movement system

[1] University of Wisconsin – La Crosse, La Crosse, WI, USA
[2] Trine University, Fort Wayne, IN, USA

Conflict of Interest: The authors report no conflicts of interest.

CORRESPONDING AUTHOR
Thomas Gus Almonroeder, DPT, PhD
Assistant Professor
University of Wisconsin – La Crosse
Department of Health Professions
Physical Therapy Program
1300 Badger St.
La Crosse, WI, USA 54601
Phone: (608) 738-6174, Fax: (608) 785-8460
E-mail: almonroeder.thomas@gmail.com

INTRODUCTION

Anterior cruciate ligament (ACL) injuries are common in sports such as basketball and soccer[1,2] and appear to be becoming more frequent over time.[3,4] The majority of ACL injuries occur during landing and do not involve direct contact with a teammate or opponent.[5–8] Female athletes are at particularly high risk for non-contact ACL injuries.[9] Surgical reconstruction of the ACL is recommended for athletes who intend to resume sports participation.[10] Unfortunately, many female athletes do not return-to-sport following ACL reconstruction[11] and those who do are at risk for developing premature knee osteoarthritis.[12] As a result, optimizing ACL injury prevention in female athletes is a key objective in sports medicine.[13]

Female athletes who exhibit a 'stiff' landing pattern, characterized by high landing forces and minimal joint flexion, appear to be at high risk for non-contact ACL injury. Prospective studies have found that female athletes who go on to sustain a non-contact ACL injury demonstrate greater vertical ground reaction forces (vGRFs) and less knee flexion during landing compared to female athletes who remain uninjured.[14,15] In addition, musculoskeletal modeling has shown that stiffer landings may place greater loads on the ACL.[16,17] Analysis of video recorded at the time of ACL injury also indicates that female athletes often exhibit a flat-footed position at initial ground contact (i.e. minimal ankle plantarflexion) and limited hip and knee flexion at the time of injury.[7,18,19] Based on this link between a stiff landing pattern and ACL injury risk, training athletes to avoid stiff landings is often incorporated as part of ACL injury prevention.[20] Optimizing landing strategies may be a key to preventing non-contact ACL injuries.[21]

Movement training for ACL injury prevention typically relies on simple verbal instructions to guide an athlete's technique.[13] Verbal instructions can promote either an internal or external attentional focus.[22] With an internal focus (IF) an individual directs their attention to an aspect of their movement (e.g. the position/motion of their knees during a landing), whereas with an external focus (EF) they attend to the effect(s) of their movement (e.g. the sound produced when they land). Clinicians appear to typically use instructions that promote an IF;[23,24] however, an EF has been shown to result in superior performance for a wide range of movement tasks.[22,25] There have been attempts to compare landing mechanics in athletes provided with instructions promoting an IF vs. an EF.[26–28] Findings from these studies appear to indicate that an EF may result in a softer landing pattern (e.g. greater knee flexion); however, the instructions provided in these studies have not been specific to the initial landing phase. For instance, Welling et al.[28] compared landing mechanics during a drop vertical jump task in athletes who had received instructions promoting either an IF or an EF. Athletes in their IF group received the instruction, 'extend your knees as rapidly as possible after landing on the force plate', while athletes in their EF group received the instruction, 'push yourself as hard as possible off the ground after landing on the force plate.' Both of these sets of instructions appear to pertain to the subsequent vertical jump (vs. absorbing energy during initial landing) and are not consistent with the types of instructions that are provided during movement training for ACL injury prevention. In addition, previous studies comparing the effects of varying types of verbal instructions on landing mechanics have not included baseline trials where athletes utilize their typical technique prior to instruction. As a result, it is difficult to determine how varying types of verbal instructions (i.e. those that promote an IF vs. an EF) influence mechanics associated with ACL injury risk.

The purpose of this study was to compare the influence of verbal instructions promoting an IF vs. an EF on landing stiffness in female athletes. It was hypothesized that both types of instructions would reduce landing stiffness vs. baseline landings performed prior to instruction. In addition, it was also hypothesized that female athletes would demonstrate a greater reduction in landing stiffness when they were provided with instructions that promote an EF, compared to when they were provided with instructions that promote an IF. The findings from this study may have relevance to sports medicine professionals involved in ACL injury prevention.

METHODS

Sixteen females between the ages of 18-30 years old participated in this cross-sectional study. Participants were required to have experience competing in Level I[29] sports at the high school and/or inter-collegiate level. Level I sports involve frequent jumping and landing (e.g. basketball). Participants also needed to report a Tegner Activity Scale[30] score of greater than 4/10, which indicates that they were regularly participating in physical activity at the time of the study. Individuals were excluded from participating if they had a history of significant lower extremity injury (e.g. fracture, ligament tear) or an injury in the previous 6 months that limited their activity. An *a priori* sample size estimate was conducted using an alpha of .05, a beta of .20, and an effect size of 0.8 ('large effect'). This sample size estimate indicated that 15 participants was sufficient to ensure adequate power for potential pairwise comparisons. A large effect was anticipated based on the results of a previous study that compared landing mechanics when participants adopted an IF vs. an EF.[26] G*Power software[31] was used for sample size estimation (Version 3.1, University of Dusseldorf, Dusseldof, DEU). This study was approved by the Institutional Review Board at Trine University and all participants provided informed consent prior to enrollment.

All testing was completed during a single session in a motion analysis laboratory. Prior to testing, 14 mm retroreflective markers were adhered bilaterally to the anterior superior iliac spines, posterior superior iliac spines, and greater trochanters, as well as to the medial and lateral femoral epicondyles, medial and lateral malleoli, and the 1st and 5th metatarsal heads of the participants' dominant limb. For this study the limb the participant reported that they would use to kick a ball farthest was considered the 'dominant' limb. Clusters of four markers attached to a rigid shell were also adhered to the thigh, leg, and heel counter of the shoe. A three-second static standing calibration trail was recorded with all markers in place. This trial was used to establish a biomechanical model which included the pelvis and the thigh, leg, and foot segments of the dominant limb. The marker clusters and the markers on the anterior superior and posterior superior iliac spines remained in place following the static calibration trial and were used to track the motion of the pelvis, thigh, leg, and foot during the movement trials. The other markers were removed following the static calibration trial.

Prior to initiating the drop landing trials, participants completed a standardized warm-up which involved alternating between bodyweight squats (2 sets x 8 repetitions) and maximal double-leg vertical jumps (2 sets x 5 repetitions). After completing the warm-up, participants performed seven drop landings from a 31 cm high box using their typical technique (baseline trials). The foot of their dominant limb was required to land on a force plate (OR6-7-2000; Advanced Mechanical Technology, Inc., Watertown, MA, USA) that recorded three-dimensional ground reaction forces at 1000 Hz. Three-dimensional marker positions were simultaneously recorded during the drop landings at 200 Hz via an 8-camera motion capture system (Vicon Motion Systems, Inc., Oxford, GBR).

After completing the baseline trials, participants were given verbal instructions intended to reduce their landing stiffness. Two different sets of instructions were provided; one promoted an IF and the other promoted an EF. The instructions given for the IF condition were, 'focus on bending your knees when you land', while the instructions given for the EF condition were, 'focus on landing softly'. Both of these instructions are commonly used as part of movement training to reduce ACL injury risk.[32–34] Participants performed seven drop landings for each of the IF and EF conditions. As a result, each participant performed 21 total drop landings (seven baseline, seven IF condition, seven EF condition). All drop landing trials were performed for a condition before moving to the next condition (i.e. participants did not alternate between the IF and EF conditions). Having participants alternate between trials for the IF and EF conditions was considered; however, there was concern among investigators that it would be difficult for athletes to switch between attentional foci. Instructions were given once prior to the set of trials for each condition. The order of the IF and EF conditions was counterbalanced by alternating which condition was performed first as participants were enrolled in the study. Participants were allowed time to rest between trials/conditions as needed; however, all participants performed the drop landings in a fairly continuous manner. Investigators considered incorporating standard rest periods; however, they decided this was not necessary since all participants were physically active on a regular basis and a high level of fatigue was not anticipated considering the demands of the drop landing task and the number of trials performed. The warm-up and testing were completed in standard footwear (Avi-Rival, AVIA; Sequential Brands Group, Inc., New York, NY, USA).

The kinematic and kinetic data were both filtered using a 4th order, zero lag, recursive Butterworth filter with a cutoff frequency of 20 Hz. Right-handed local coordinate systems were established to describe the position and orientation of the body segments. The pelvis segment was established using the markers on the anterior superior and posterior superior iliac spines. The hip joint center was estimated using a regression approach.[35,36] The knee joint center was estimated by finding the midpoint between the markers on the medial and lateral femoral epicondyles and the ankle joint center was estimated by findings the midpoint between the markers on the medial and lateral malleoli. The distal end of the foot was considered the midpoint between the markers on the 1st and 5th metatarsal heads. Hip, knee, and ankle joint angles were calculated for each of the landing trials using a joint coordinate system approach.[37,38] All data processing was performed using Visual3D software (C-Motion, Inc., Germantown, MD, USA).

The initial two trials for each condition were not analyzed, as these trials were included to allow participants to become acclimated to the task/instructions. Only data from the final five trials in each condition were analyzed. The kinetic variables of interest were the peak vGRF and the time from initial contact (IC) to the peak vGRF (time-to-peak). Initial contact was defined as the point during the landing where the vGRF first exceeded 20 N.[32,39] Joint kinematics from IC to the time of the peak vGRF were also examined.[34,40] This early landing phase may be particularly relevant to ACL injury risk, as previous studies indicate that ACL injuries likely occur shortly after landing (within the initial 50 ms)[6,19] and peak ACL loading also appears to occur during this time frame.[41,42] The kinematic variables of interest were the sagittal plane ankle, knee, and hip angles at IC and at the time of the peak vGRF. Leg stiffness was also analyzed by dividing the peak vGRF by the vertical excursion of the center of mass of the pelvis from initial contact to the time of the peak vGRF (initial contact position minus the minimum position).[43,44] The pelvis center of mass was estimated based on the pelvis markers. Higher leg stiffness values are indicative of a stiffer landing pattern. The dependent variables of interest were identified for each trial and the five-trial means were calculated for each participant. A custom MATLAB script was used to identify the dependent variables from the time series (The MathWorks, Inc., Natick, MA, USA). Repeated-measures ANOVA was used to compare the dependent variables across the conditions (baseline, IF, EF). A Greenhouse-Geiser correction was used when the assumption of sphericity was violated. Fisher's least significant difference post hoc tests were conducted in the case of a significant omnibus test. An alpha of .05 was used for each statistical test. The 95% confidence interval (95% CI) was also calculated for the pairwise comparisons. Statistical analysis was conducted using SPSS software (Version 25; IBM Corp., Armonk, NY, USA).

RESULTS

The participants' ages, masses, heights, and Tegner scores are presented in Table 1.

The repeated measures ANOVAs indicated that there were differences among the conditions for the peak vGRF ($p < .001$), time-to-peak vGRF ($p = .004$), leg stiffness ($p < .001$), hip IC angles ($p < .001$), hip angles at peak vGRF ($p < .001$), knee IC angles ($p < .001$), and knee angles at peak vGRF ($p < .001$) (Table 2). There were no differences among the conditions for the ankle IC angles ($p = .206$) or the ankle angles at peak vGRF ($p = .583$) (Table 2).

Table 1. *Participant Characteristics.*

	Mean ± SD or median (range)
Age (years)	21.81 ± 2.59
Mass (kg)	70.58 ± 13.68
Height (m)	1.68 ± 0.06
Tegner score	5.5 (5-9)

Table 2. *Dependent variables of interest for each condition.*

	Baseline	IF	EF	p-value
Leg stiffness (Nkg^{-1}/m)	110.4 ± 38.8	84.0 ± 38.1*	69.5 ± 17.9*†	<.001
Hip IC angles (°)	30.8 ± 8.1	36.7 ± 9.1*	36.5 ± 9.6*	<.001
Hip angles at peak vGRF (°)	46.6 ± 10.1	54.5 ± 10.0*	55.4 ± 12.0*	<.001
Knee IC angles (°)	15.7 ± 6.3	21.0 ± 6.5*	21.6 ± 5.9*	<.001
Knee angles at peak vGRF (°)	49.0 ± 8.6	56.0 ± 9.5*	59.4 ± 9.6*†	<.001
Ankle IC angles (°)	-25.4 ± 7.7	-22.6 ± 9.4	-24.4 ± 9.6	.206
Ankle angles at peak vGRF (°)	14.7 ± 10.2	15.8 ± 6.7	16.1 ± 5.6	.583
Peak vGRF (Nkg^{-1})	18.1 ± 3.6	14.6 ± 3.5*	13.6 ± 2.4*	<.001
Time-to-peak vGRF (ms)	54.4 ± 12.7	53.9 ± 13.8	62.4 ± 11.8*†	.004

Means ± standard deviations; p-values based on omnibus test
IF = internal focus; EF = external focus; IC = initial contact; vGRF = vertical ground reaction force; Nkg^{-1} = Newtons per kilogram; ms = milliseconds
* indicates significant difference vs. baseline; † indicates significant difference vs. IF condition ($p < .05$)
Positive angles are indicative of hip flexion, knee flexion, and ankle dorsiflexion

Post hoc pairwise comparisons indicated that peak vGRFs were lower for the IF ($p < .001$; 95% CI [-4.73, -2.28]) and EF ($p < .001$; 95% CI [-5.98, -3.06]) conditions vs. baseline; however, there was no difference in the peak vGRFs between the IF and EF conditions ($p = .089$ 95% CI [-0.17, 2.20]) (Table 2). The time-to-peak vGRF was longer for the EF condition compared to the baseline ($p = .018$; 95% CI [1.56, 14.52]) and IF conditions ($p = .005$; 95% CI [3.00, 14.08]); however, there was no difference in the time-to-peak vGRF between the IF and baseline conditions ($p = .821$; 95% CI [-5.10, 4.11]) (Table 2). Participants demonstrated less leg stiffness for the IF ($p < .001$; 95% CI [-37.71, -15.05]) and EF ($p < .001$; 95% CI [-56.87, -24.92]) conditions vs. baseline, as well as less leg stiffness for the EF condition vs. the IF condition ($p = .047$; 95% CI [-28.83, -0.20]) (Table 2).

Post hoc pairwise comparisons indicated that participants demonstrated more hip flexion at IC for the IF ($p < .001$; 95% CI [3.66, 8.17]) and EF ($p < .001$; 95% CI [3.26, 8.17]) conditions vs. baseline; however, there was no difference in IC hip flexion angles between the IF and EF conditions ($p = .786$; 95% CI [-1.36, 1.76]) (Table 2). Participants also demonstrated more hip flexion at peak vGRF for the IF ($p < .001$; 95% CI [5.00, 10.78]) and EF ($p < .001$; 95% CI [5.26, 12.25]) conditions vs. baseline; however, there was no difference in hip flexion at peak vGRF between the IF and EF conditions ($p = .395$; 95% CI [-2.98, 1.25]) (Table 2).

Post hoc pairwise comparisons indicated that participants demonstrated more knee flexion at IC for the IF ($p < .001$; 95% CI [3.08, 7.58]) and EF ($p < .001$; 95% CI [3.22, 8.65]) conditions vs. baseline; however, there was no difference in IC knee flexion angles between the IF and EF conditions ($p = .451$; 95% CI [-2.27, 1.06]) (Table 2). Participants also demonstrated more knee flexion at peak vGRF for the IF ($p < .001$; 95% CI [3.74, 10.27]) and EF ($p < .001$; 95% CI [6.30, 14.50]) conditions vs. baseline, as well as more knee flexion at peak vGRF for the EF condition vs. the IF condition ($p = .008$; 95% CI [1.05, 5.74]) (Table 2).

DISCUSSION

The purpose of this study was to compare the influence of verbal instructions promoting an IF vs. an EF on landing stiffness in female athletes. Both sets of instructions resulted in lower vGRFs, greater hip and knee flexion, and less leg stiffness during landing (vs. baseline trials performed prior to instruction). These adaptations are indicative of a softer landing pattern and would likely reduce ACL injury risk. The findings from this study are consistent with those of earlier studies which have found that simple verbal instructions can have immediate positive effects on athletes' landing mechanics.[32,45] In addition, participants in this study demonstrated a longer time-to-peak vGRF, greater knee flexion, and less leg stiffness when provided with instructions that promoted an EF, compared to when they were provided with instructions that promoted an IF. This appears to indicate that providing instructions that promote an EF may have a greater effect on landing stiffness vs. those that promote an IF. Clinicians should consider providing instructions that promote an EF when training athletes to avoid stiff landings.

A primary function of the ACL is to limit anterior translation of the tibia relative to the femur.[46] Anterior shear forces produced by the quadriceps musculature act to translate the tibia anteriorly, which loads/strains the ACL. However, these shear forces are minimized as the knee moves beyond relatively shallow knee flexion angles (e.g. $>30^\circ$),[47–49] which is likely the result of a reduction in the angle between the patellar tendon and the tibial shaft.[50] In addition, the hamstrings musculature becomes more effective at assisting the ACL in limiting anterior tibial translation as the knee flexes.[47,49] This is likely caused by an increase in the angle between the line of pull of the hamstrings and the long axis of the tibia.[50] As a result, the greater degree of knee flexion at the time of the peak vGRF when athletes were provided with instructions promoting an EF, vs. when they were provided with instructions promoting an IF, may help to reduce ACL loading/strain. It appears that the shift in timing of the peak vGRF to later during the landings for the EF condition allowed participants to reach safer knee positions by the time the vGRF reached its peak.

The advantages of an EF versus an IF with respect to motor performance/learning has been explained by the constrained action hypothesis.[51] The constrained action hypothesis proposes that when an individual focuses on their movements (i.e. adopts an IF) they may interfere with the automatic control processes that regulate a movement pattern; whereas when they adopt an EF they allow the motor system to self-organize, which will often result in a more optimal movement pattern. The results of this study appear to fit this premise. The goal of the instructions for the IF and EF conditions were to reduce landing stiffness. Both sets of instructions significantly reduced leg stiffness vs. baseline; however, the instructions that promoted an EF resulted in a greater reduction in stiffness during the landings compared to the instructions that promoted an IF. This would appear to indicate that participants were able to develop a more optimal kinematic solution to reduce landing stiffness when they adopted an EF.

While the findings from this study may make a valuable contribution to an important body of literature, there are limitations that need to be acknowledged. First, it is important to note that this study only examined the immediate effects of verbal instruction on landing mechanics. As a result, it cannot be determined if there are differences in retention, transfer, and/or movement automaticity when athletes are given instructions promoting varying attentional foci. In addition, this study examined mechanics during a double-leg landing task. While athletes are often performing a double-leg landing at the time of ACL injury[6] and a double-leg landing task is commonly used for movement training,[33,52,53] future studies should consider analyzing more demanding tasks that are routinely performed by athletes such as single-leg landings or lateral cutting. Participants were also not asked to report what they were attending to during or after testing. As a result, it cannot be determined if participants followed the instructions they were provided. Finally, athletes who had previously participated in a structured ACL injury prevention program were not excluded from this study, which may have limited the effects of instruction for some participants. Although not a limitation, it is also important to note that the differences observed between the EF and the IF conditions were subtle. For example, the difference in knee flexion at the peak vGRF was less than 4°. It is possible that differences of this magnitude may not have a meaningful influence on ACL injury risk.

While this study was framed around ACL injury prevention, the findings may have relevance to prevention of other types of acute and overuse lower extremity injuries. It is also possible that the findings of this study may apply to movement training for injured athletes who are rehabilitating (e.g. post ACL reconstruction). Future studies should continue to examine how attentional focus influences the effectiveness of movement training for primary and secondary injury prevention and rehabilitation.

CONCLUSION

The results of this study indicate that participants exhibited lower vGRFs, greater hip and knee flexion, and less leg stiffness during landing after receiving instructions intended to reduce their landing stiffness. Participants also demonstrated greater knee flexion and less leg stiffness when provided with instructions that promoted an EF, compared to when they were provided with instructions that promoted an IF. These results appear to indicate that clinicians should provide instructions that promote an EF when training female athletes to avoid stiff landings.

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