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Biomechanical Deficits at the Hip in Athletes With ACL Reconstruction Are Ameliorated With Neuromuscular Training

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Abstract

Background: The efficacy of a neuromuscular training (NMT) program to ameliorate known hip biomechanical risk factors for athletes with anterior cruciate ligament reconstruction (ACLR) is currently unknown.

Purpose/Hypothesis: The purpose was to quantify the effects of an NMT program on hip biomechanics among athletes with ACLR and to compare posttraining hip biomechanics with a control group. The hypotheses were that known hip biomechanical risk factors of anterior cruciate ligament (ACL) injury would be significantly reduced among athletes with ACLR after the NMT program and that posttraining hip biomechanics between the ACLR and control cohorts would not differ.

Study Design: Controlled laboratory study.

Methods: Twenty-eight athletes (n = 18, ACLR; n = 10, uninjured) completed a 12-session NMT program. Biomechanical evaluation of a jump-landing task was done before and after completion of the program. Repeated measures analysis of variance was performed to understand the effect of NMT within the ACLR cohort. Two-way analysis of variance was used to compare both groups. Post hoc testing was done for significant interactions. Hip biomechanical variables at initial contact are reported.

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Results: The athletes with ACLR who completed the NMT program had a significant session × limb interaction (*P* = .01) for hip external rotation moment and a significant main effect of session for hip flexion angle (*P* = .049) and moment (*P* < .001). There was a significant change for the involved (*P* = .04; 528% increase) and uninvolved (*P* = .04; 57% decrease) limbs from pre- to posttraining for hip rotation moment. The ACLR cohort had an increase in hip flexion angle (14% change) and a decrease in hip flexion moment (65% change) from pre- to posttraining. Posttraining comparison for these same hip biomechanical variables of interest revealed no significant interactions (*P* > .05) between the ACLR and control cohorts. There was a significant main effect of group (*P* = .02) for hip flexion angle, as the ACLR cohort demonstrated greater hip flexion angle than that of the control group.

Conclusion: For athletes with ACLR, hip biomechanical measures of ACL injury risk show significant improvements after completion of an NMT program.

Clinical Relevance: Athletes with ACLR who are participating in an NMT program may ameliorate known hip biomechanical risk factors for an ACL injury.

Keywords

anterior cruciate ligament; ACL reconstruction; neuromuscular training

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Anterior cruciate ligament (ACL) tears are debilitating sports-related injuries that disproportionately affect young active athletes.[28,44] The US standard of care for athletes with ACL injury who desire to return to their preinjury levels of sport is ACL reconstruction (ACLR). However, aberrant movement strategies and muscle weakness persist for these athletes beyond the typical return-to-sport time frame of 6 to 12 months.[22,23,39,42] Importantly, these chronic measurable deficits among athletes with ACLR increase the risk of further knee injury and alter the loading of the articular cartilage, leading to its eventual degeneration.[1,2,8,39] The current evidence indicates that young athletes at return to activity are a highly vulnerable cohort who have the greatest risk for a second ACL injury.[49,50] Similar to primary ACL injuries, the majority of second ACL injuries are sustained as noncontact episodes, which indicates that biomechanical and neuromuscular control of the lower extremities is an important risk factor.[51]

Poor neuromuscular and biomechanical control proximal to the knee can cause deleterious forces across the knee joint.[40] There is a direct association between neuromuscular deficits at the trunk and hip and an increased risk of ACL injury.[5,21,40,52,53] Two prospective biomechanical-epidemiological studies observed that decreased core proprioception and deficits in neuromuscular control of the trunk predict knee and ACL injury with great sensitivity and specificity.[52,53] Prospective studies that screened young active athletes who were uninjured or had undergone ACLR before the beginning of the season indicated that athletes who demonstrated deficits in hip neuromuscular control during a jump landing went on to sustain a noncontact second ACL injury.[19,39] More recently, an investigation of approximately 500 athletes revealed that preseason deficits in isometric hip abduction and external rotation strength were independent predictors for future primary noncontact ACL injury in male and female athletes.[24] Therefore, correction of neuromuscular and biomechanical deficits at the hip among athletes with ACLR may allow them to safely return to sport.

Neuromuscular training (NMT) programs effectively modify high-risk biomechanics, increase neuromuscular control of the lower extremities, and reduce the incidence of ACL injuries in groups of healthy athletes.[18,20,29,36,43,45] Previous studies implementing trunk- and hip-focused NMT programs demonstrated an increase in hip abduction strength, which may translate to greater frontal plane control of the knee.[32,47] However, these studies largely focused on the uninjured healthy group of athletes. A paucity of investigations implemented and quantified the effectiveness of an NMT program for athletes with ACLR. These NMT programs may augment post-ACLR rehabilitation to address known biomechanical risk factors for second ACL injury and possibly create a safer and effective transition back to sport.[16] Therefore, the purpose of this investigation was to quantify the effects of an NMT training program on hip biomechanics and neuromuscular control in an ACLR cohort. Second, this study sought to frame posttraining hip biomechanics of an ACLR cohort with reference to the same measures for a group of uninjured control athletes who also participated in the NMT program. The primary hypothesis tested was that the measured hip biomechanics (hip external rotation moment, hip flexion moment, and hip flexion angle) associated with greater risk of ACL injury would be significantly reduced among athletes with ACLR after participation in an NMT program. It was further hypothesized that hip biomechanics in the ACLR cohort after NMT would not differ from hip biomechanics in the control cohort that completed the same NMT program.

METHODS

Subjects

Eighteen (n = 18) athletes who underwent ACLR with a hamstring tendon autograft and 10 uninjured control athletes participated in the study. The athletes with ACLR were approximately 8 months postsurgery at the time of the pretesting. The control group had no history of lower extremity injury or surgery. Table 1 includes the demographic data of both groups of athletes who participated in the study. All subjects aged ≥18 years signed an informed consent document that had been approved by the institutional review board at The Ohio State University. Written parental permission was obtained for subjects aged <18 years, as well as Institutional Review Board–approved informed assent.

Clinical Evaluation

A licensed physical therapist or athletic trainer conducted the clinical examinations. All clinicians involved in research were thoroughly trained by a single physical therapist with 7 years of experience to standardized methods. The purpose of the clinical examination was to partially determine that it was safe for the subject to perform the dynamic tasks necessary for completion of the testing session and participation in the NMT program. To participate in the study, athletes were required to demonstrate <30% deficit in isokinetic knee extension at 60 deg/s, 11 knee joint effusion or less,[46] pain-free knee range of motion, and multiple single-legged hops in place for maximum height without any pain. The clinician had the right to withhold the athlete from participating in the biomechanics testing if the individual was deemed unsafe based on the quality of the single-legged hop in place (ie, a stiff landing with excess frontal plane movement).

Biomechanical Testing

Identical biomechanics testing sessions were completed pre- and posttraining by all athletes participating in the study. First, the subjects were outfitted with a modified Helen Hayes-style marker set consisting of 55 retroreflective markers. The marker set was previously described in detail.[4] Three trained experienced researchers placed markers on the study participants, and intersubject reliability was measured for peak hip flexion (intraclass correlation coefficient [ICC], 0.715; standard error of measurement [SEM], 4.88; minimal detectable change [MDC], 13.5), peak hip adduction (ICC, 0.845; SEM, 1.03; MDC, 2.9), peak hip abduction (ICC, 0.937; SEM, 1.28; MDC, 3.5), and peak hip external rotation (ICC, 0.947; SEM, 1.25; MDC, 3.5). Next, the athletes performed 5 successful drop vertical jumps (DVJs), which were captured with a 12-camera motion analysis system (Raptor 12; Motion Analysis Corp). The DVJ task was described by Hewett et al,[19] and it involved a bilateral drop-landing task from a 31-cm-tall box. Before performance of the task, the athletes were given oral instructions on how to perform the DVJ, had the task demonstrated to them, and were allowed at least 2 or 3 practice trials (or more if needed) to orient to the task. A trial was successful when the athlete dropped from the box, with both feet leaving simultaneously, and landed with each foot on separate embedded force plates, followed by an immediate maximum effort vertical jump. The 3-dimensional marker positions were sampled at 240 frames per second. Separate ground-reaction forces for each limb were collected at a rate of 1200 Hz with force plates embedded into the floor (Bertec 6090; Bertec Corp).

Neuromuscular Training

The NMT program consisted of 12 training sessions that were supervised by physical therapists, strength and conditioning coaches, athletic trainers, or a graduate student within the laboratory. Before beginning the study, the trainers underwent their own supervised training to ensure consistency in program implementation, including progression and extrinsic cueing. Depending on their schedules, athletes typically met with the NMT trainer for approximately 1 hour, 2 times a week, for 6 weeks. Each athlete completed all 12 training session before participating in the posttraining biomechanics testing.

The NMT program was developed according to Di Stasi et al (Appendix, available in the online version of this article).[9] In short, the program consisted of 7 exercise progressions: single-legged exercises (single-legged hop and anterior progressions), posterior chain activation exercises (Romanian dead lift and lunge progressions), bilateral jumping exercises (double-legged jump progression), and core stability and trunk strengthening exercises (prone trunk stability and lateral trunk flexion progressions). Each exercise progression consisted of 4 levels of increasing difficulty, and advancement to the next level was determined per individual performance rather than training session number. The decision to advance the athlete was made by the trainer and based on the ability of the athlete to execute proper form for at least 3 full sets of 10 repetitions. Because of these performance-based progression criteria, not all athletes achieved the same performance levels for each progression by their 12th session.

Data Treatment and Statistical Analysis

Customized software was used to reduce and analyze kinematic and kinetic data. Marker position gaps that were within the 25 consecutive frames during the jump-landing task were filled with a cubic spline function in Cortex (v 4.1; Motion Analysis Corp). After all markers were properly labeled and the gaps were filled, these data were exported to Visual 3D (C-Motion Inc). First, customized static models scaled to each subject's anthropometrics were generated. Next, the marker position data and the ground-reaction force data were low pass filtered with a bidirectional Butterworth filter at 12 and 50 Hz, respectively. Hip joint center was determined with anatomic indices. All data were time normalized to 100% of stance such that initial contact (0% stance) was defined as the frame of data when the vertical component of the ground-reaction force (vGRF) exceeded 10 N and takeoff dropped <10 N. Kinematics and kinetics were calculated with the Cardan-Euler sequence for local coordinate systems and inverse dynamics, respectively. These calculations were processed with custom codes in Visual 3D (C-Motion Inc) and MATLAB (Mathworks Inc).

The analysis focused on the effect of NMT on hip biomechanical variables at initial contact because injuries typically occur within approximately the first 20 to 50 milliseconds of landing.[25] Therefore, the biomechanical variables presented in this study are values at initial contact during the landing phase of the DVJ task. However, since initial contact was based on vGRF exceeding 10 N, we report peak vGRF instead. In addition, to understand the effect of NMT within our ACLR cohort, a repeated measures analysis of variance was conducted to assess interactions and main effects of session (pre- and posttraining) and limb (involved and uninvolved) on discrete hip kinematic and kinetic variables. Second, to understand if there were differences between the ACLR and control groups after both finished the NMT program, we conducted 2-way analysis of variance to assess the interactions and main effects of group (ACLR and control) and limb (involved/dominant and uninvolved/nondominant) on the variables of interest. The involved and dominant limbs were grouped together and the uninvolved and the nondominant limbs were grouped together. Post hoc *t* tests were utilized to determine differences when a significant interaction was found. A chi-square test for independence was conducted for categorical demographic data. Alpha level was set to 0.05 a priori.

RESULTS

Four athletes with ACLR who were initially enrolled in the study did not meet the clinical criteria to participate. These athletes were referred back to their physical therapist to continue working on their deficits. Five athletes with ACLR did not return for posttraining biomechanical evaluation of hip biomechanics, and 2 athletes were excluded because they did not have an ACL injury or ACLR. Eighteen athletes with ACLR and 10 controls completed all 12 sessions of the NMT program and the pre- and posttraining biomechanical evaluation of a DVJ.

Hip Biomechanical Changes in Athletes With ACLR

Table 2 displays a summary of the rest of the pre- and posttraining hip kinematic and kinetic variables for the ACLR group.

There was a significant session × limb interaction ($P = .01$) for hip external rotation moment. Post hoc testing showed a significant increase in the net hip external rotation moment of the involved limbs after NMT ($P = .039$), while the uninvolved limbs had a significant decrease after NMT ($P = .04$).

There were no significant session × limb interactions for hip flexion angle ($P = .694$), hip abduction angle ($P = .135$), hip flexion moment ($P = .728$), or hip abduction moment ($P = .409$). However, a significant main effect of session was observed for hip flexion angle ($P = .049$) and hip flexion moment ($P < .001$). After training, the athletes with ACLR landed with more hip flexion but lower hip flexion moments. In addition, a significant main effect of limb was observed for hip flexion angle ($P = .023$), hip flexion moment ($P = .027$), and hip abduction moment ($P = .029$). Compared with the uninvolved limbs, the involved limbs had greater hip flexion angles, lower hip flexion moments, and greater hip abduction moment.

There was no significant session × limb interaction for peak vGRF ($P = .736$). However, a significant main effect of limb ($P = .012$) was observed for peak vGRF, indicating that the involved limbs contacted the ground with lower vGRF than the uninvolved limbs.

Posttraining Hip Biomechanics Comparison Between ACLR and Control Cohorts

Table 3 displays a summary of the posttraining hip kinematic and kinetic variables for the ACLR and control groups.

There was a significant group × limb interaction observed for hip abduction moment ($P = .04$) and peak vGRF ($P = .04$). Post hoc testing showed that the involved ($P = .01$) and uninvolved ($P = .04$) limbs of the athletes with ACLR had significantly lower hip abduction moments when compared with the dominant limbs of the control group. Within the control group, the dominant limb had greater hip abduction moment than the nondominant limbs ($P = .01$). Also, post hoc testing for vGRF showed that the involved limbs of the ACLR group showed significantly lower ($P = .01$) force than the uninvolved limbs of the same group. In addition, the involved limbs of the ACLR group had significantly lower ($P = .04$) vGRF than the dominant limbs of the control group.

There was no significant session × limb interaction for hip flexion angle ($P = .49$), hip abduction angle ($P = .09$), hip external rotation moment ($P = .33$), and hip flexion moment ($P = .90$). However, there was a significant main effect of group ($P = .020$) for hip flexion angle and significant main effect of limb ($P = .01$) for hip abduction angle. Compared with the control group, the ACLR group landed with greater hip flexion after training, and the involved limbs demonstrated greater hip abduction versus the uninvolved limbs.

DISCUSSION

The findings of our study support our hypotheses: (1) the NMT program would significantly improve known hip biomechanical risk factors associated with greater risk of ACL injury among the athletes with ACLR, and (2) these same athletes would demonstrate similar posttraining hip biomechanics when compared with a control group. The NMT program ameliorating hip biomechanical risk factors for ACL injury has important clinical relevance. The results indicated that the ACLR group's involved limbs had a significant increase in hip external rotation moment with training. In a previous prospective study by Paterno and colleagues,[39] the athletes with ACLR who landed with decreased hip external rotation moment during early landing and a net hip internal rotation moment at initial contact were 8 times more likely to experience a second ACL injury than were the athletes with greater hip external rotation moment. In addition, after training, the ACLR group landed with significantly greater hip flexion and lower hip external flexion moments during the jumplanding task. Importantly, deficits in these same biomechanical variables in combination with other variables were implicated in greater risk for ACL injury.[19,39] This evidence shows the potential role for NMT in the effective correction of post-ACLR hip biomechanical and neuromuscular deficits.

A paucity of studies have investigated the efficacy of NMT programs on lower extremity biomechanics in athletes with ACLR. The earliest form of a training program being implemented for athletes with ACL injury to improve gait biomechanics was perturbation training, which is designed to improve dynamic stability of the knee and coactivation of surrounding musculature.[10,12,15] However, this type of training involves the guided manipulation of movable support surfaces and not a dynamic movement-based training program.[12] The current study implemented a targeted NMT program that targeted all modifiable components of the second ACL injury risk profile.[9] This movement training program elicited the coordination of the trunk and lower extremities and required the activation of muscles that are commonly reported as weak at the time of return to sport and movements that replicate conditions experienced during sports.[9] A recent report from Capin et al[7] investigated the effect of movement-based training for athletes with ACLR. These researchers compared the gait mechanics of a group of men who postoperatively underwent perturbation training combined with strength, agility, and secondary prevention training with a group who received only the secondary prevention training. They found no significant differences between the groups for the biomechanical gait variables; however, persistent interlimb gait asymmetries were observed at 1 and 2 years, despite improvement in gait asymmetries from that same period. Furthermore, a few studies reported on the effect of NMT programs on clinical and self-reported outcomes in this same ACLR cohort, with generally positive but conflicting results.[3,11,30,41] However, the evidence in the literature in combination with the data presented in the current study indicates that NMT may address biomechanical deficits among athletes with ACLR and potentially reduce their risk for future sequelae.[10,14] In addition, to our knowledge, this study is the first to present improvements in hip neuromuscular and biomechanical control in a cohort of athletes with ACLR during a previously validated and highly predictive of an ACL injury jumpinglanding task.

A secondary aim of the present study was to compare the posttraining biomechanics of athletes with ACLR and a group of uninjured athletes after both groups completed the same training program. Past studies focused on implementation of NMT programs in uninjured athletes to improve function and prevent lower extremity injuries. The current evidence indicates that uninjured athletes who participate in NMT programs can enhance their functional performance,[20,33,35] improve landing biomechanics and ameliorate known biomechanical risk factors of lower extremity injury,[17,20,27,33] and prevent lower extremity injuries.[18,31,35,45] The findings of this study indicate comparable posttraining hip biomechanics during a jumplanding task between the ACLR and control groups, with a few exceptions. The athletes with ACLR did demonstrate greater hip flexion angle after training as compared with the control group; however, there were no significant differences between the groups for hip flexion moment and hip external rotation moment. This suggests that athletes with ACLR who are participating in NMT programs after postoperative rehabilitation and before returning to sport may recover hip biomechanics and neuromuscular control similar to that of an uninjured group of athletes. The unique challenge during postoperative physical therapy for many clinicians is to not only target residual impairments after ACLR but also mitigate the risk of subsequent ACL injury. Based on the exceedingly high rates of second ACL injury in young athletes, especially early after returning to sport,[38,39,49,50] it is inadequate to simply return the athlete back to the preinjury level of functional performance but to improve it. The current study shows that NMT after postoperative physical therapy may improve known hip biomechanical deficits associated with increased risk of ACL injury and that these athletes have biomechanical movement patterns similar to those of uninjured athletes.

The athletes with ACLR in our study were approximately 8 months out from surgery and had not returned to previous levels of activity. Despite stringent strength and clinical criteria to participate in the study, these athletes still had hip biomechanical deficits that were eventually ameliorated by participation in the NMT program. A recent investigation found that even after patients passed objective return-to-sport criteria, 7 of 14 with ACLR sustained a second ACL injury within 20 months after surgery.[6] In this study, the athletes who sustained a second ACL injury had gait biomechanics that were indicative of a more normal gait pattern, had postoperative impairments resolved earlier, and reached criterion-based return-to-sport benchmarks earlier than the athletes with ACLR who did not go on to further injury. These biomechanical measures are difficult to include in return-to-play decision making despite their sensitivity and specificity because of the limited availability of the resources, equipment, and expertise in the clinical setting. Therefore, clinician researchers utilize more clinical factors that are able to predict a second ACL injury in this population. Kyritsis et al[26] found that not meeting 6 clinical discharge criteria, which included a combination of strength, running *t* test, and the 3 clinical hops (single, triple, and triple crossover), before return to sport increased the risk of graft rupture 4-fold. More recently, a group of researchers reported on the development of a clinical decision algorithm to identify young patients at high risk of a second ACL injury within 24 months after return to sport.[37] They observed that clinically available measures, such as age, sex, confidence, and triple hop for distance and limb symmetry, can be used to determine the individuals who are at risk for a second ACL injury. More research is needed to develop more sensitive return-to-sport criteria that include clinical data, self-reported outcomes, and biomechanical and neuromuscular variables. However, despite all these factors that may influence injury risk, the current findings concur with recent evidence that a delay in return to sport for at least 9 months after ACLR may mitigate overall risk of a second ACL injury.[13,34]

The current study is not without limitations. The sample sizes are relatively low, and the numbers between the groups are uneven. Given that our primary variables of interest showed a significant change after NMT, we do not think that the study power was compromised. Ultimately, the current study is a step forward in presenting the efficacy of NMT on hip biomechanics in athletes with ACLR. Future studies with larger cohorts and a randomized study design would be the optimal approach to validate the effect of this type of training. However, for this study, the athletes in both groups were young, highly active individuals, and there were no significant differences in demographics. An NMT program that incorporates plyometric-based exercises and heavy demands across the lower extremities may expose the athletes with ACLR to deleterious knee loads. Therefore, a clinical examination was used as a screen to ensure selection of athletes who demonstrated a baseline level of performance to avoid undue risk of injury during the various jumping and landing tasks. This may have led to a selection bias toward the highest-functioning athletes with ACLR.

It is important to note that the athletes with ACLR all received a hamstring tendon autograft, and previous studies indicated graft-specific biomechanical changes of the lower extremities. Some of these studies observed that individuals who received a hamstring tendon autograft had worse lower extremity strength and function than the ones who received a patellar tendon. Also, despite the improvements in hip biomechanics after training, athletes with ACLR may experience biomechanical asymmetries between limbs. These functional asymmetries have been implicated in increased risk of injury, and future studies will delineate the effect of NMT on these deficits.

In addition, a requirement for all athletes from both groups was to complete 12 NMT sessions. The progress of each athlete during the training was not tracked by the research team, and athletes finished at varying performance levels within each exercise progression. As mentioned earlier, the decision to advance the athlete to the next exercise was based on the athlete’s ability to consistently perform the exercise with proper technique. A meta-analysis observed that attendance and completion of the prescribed sessions are integral to the prevention of ACL injuries in uninjured athletes.[48] However, despite not completing all the exercises within the training program, the athletes with ACLR still demonstrated improved hip biomechanical and neuromuscular control. A greater improvement in hip biomechanical control may be anticipated if all athletes completed all the exercises within the NMT program. Future studies are ongoing to address these limitations, in addition to a long-term follow-up to investigate the retention of the NMT and the incidence of reinjury for the athletes with ACLR.

CONCLUSION

The findings of this study indicate that hip biomechanical and neuromuscular deficits among athletes with ACLR may be addressed through an NMT program. In addition, after comparison of posttraining hip biomechanics during the jump-landing task between these athletes with ACLR and controls, the results indicate that these athletes demonstrate comparable hip biomechanics. This has important clinical relevance because biomechanical deficits of the lower extremities after ACLR are implicated in the debilitating sequelae commonly reported for these athletes. To target these movement impairments is critical to the future health of athletes with ACLR. This study provides early evidence that NMT may be an effective intervention to ameliorate biomechanical deficits in athletes with ACLR before returning to sport.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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TABLE 1

Demographic Data of Study Participants[a]

	ACLR	Control	*P* Value
Athletes	18	10	
Age, y	19.4 ± 7.2	16.0 ± 3.7	.12
Weight, kg	72.3 ± 15.4	73.1 ± 24.4	.62
Height, m	1.68 ± 0.1	1.66 ± 0.1	.93
Sex[b]			
Men	8	4	
Women	10	6	
Time from surgery, mo	7.7 ± 3.7	—	

[a]Values are presented as n or mean ± SD. ACLR, anterior cruciate ligament reconstruction.

[b]$\chi^2 = 0.052$.

TABLE 2

Pre- and Posttraining Hip Kinematic and Kinetic Variables for the ACLR Group[a]

	Pretraining		Posttraining		
	Involved	**Uninvolved**	**Involved**	**Uninvolved**	***P* Value**[b]
Hip angle					
Flexion	31.8 ± 9.4	30.1 ± 10.5	36.5 ± 9.3	34.2 ± 9.1	Limb, .023; session, .049
Abduction	−6.4 ± 2.6	−7.9 ± 3.1	−8.0 ± 3.0	−7.3 ± 2.3	
Hip moment					
Flexion	0.54 ± 0.3	0.6 ± 0.4	0.2 ± 0.2	0.2 ± 0.1	Limb, .027; session, <.001
Abduction	− 0.02 ± 0.2	− 0.09 ± 0.1	− 0.009 ± 0.1	− 0.04 ± 0.1	Limb, .029
External rotation	0.006 ± 0.04	0.06 ± 0.05	0.04 ± 0.05	0.02 ± 0.04	Session × limb, .015
Peak vGRF	14.8 ± 5.7	16.6 ± 6.7	13.9 ± 2.3	16.3 ± 3.8	Limb, .01

[a]All variables are at initial contact and presented as mean ± SD. Angles are presented as degrees and moments as N·m/kg. ACLR, anterior cruciate ligament reconstruction; vGRF, vertical ground-reaction force.

[b]Interactions and main effects.

TABLE 3

Posttraining Hip Kinematic and Kinetic Variables of the ACLR and Control Groups[a]

	ACLR Group		Control Group		
	Involved	**Uninvolved**	**Dominant**	**Nondominant**	***P* Value**[b]
Hip angle					
Flexion	36.5 ± 9.3	34.2 ± 9.2	28.9 ± 7.6	30.1 ± 7.5	Group, .02
Abduction	− 8.0 ± 3.0	− 7.3 ± 2.3	− 8.5 ± 2.3	− 5.2 ± 3.8	Limb, .01
Hip moment					
Flexion	0.20 ± 0.2	0.22 ± 0.2	0.13 ± 0.3	0.2 ± 0.1	
Abduction	− 0.01 ± 0.1	− 0.04 ± 0.1	− 0.1 ± 0.1	− 0.02 ± 0.1	Group × limb, .046
External rotation	0.04 ± 0.05	0.02 ± 0.05	− 0.003 ±0.05	0.01 ± 0.06	
Peak vGRF	13.9 ± 2.3	16.3 ± 3.8	15.7 ± 3.0	14.5 ± 2.9	Group × limb, .04

[a]All variables are at initial contact and presented as mean ± SD. Angles are presented as degrees and moments as N·m/kg. ACLR, anterior cruciate ligament reconstruction; vGRF, vertical ground-reaction force.

[b]Interactions and main effects.