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Variation in Response to Limb Loading Instruction on Knee Mechanics During Squatting in Early Recovery After Anterior Cruciate Ligament Reconstruction

Susan Sigward, PT, ATC, PhD; Willa Ma, BS

Human Performance Laboratory, Division of Biokinesiology and Physical Therapy, University of Southern California, Los Angeles

Context: On average, individuals in early recovery after anterior cruciate ligament reconstruction (ACLr) improve limb loading symmetry (LLS) with instruction to equalize weight distribution between limbs during squats. However, the extent to which these instructions improve knee extensor loading symmetry (KLS) or reduce intralimb compensations is not known.

Objectives: Determine how limb loading instructions influence knee and intralimb loading in individuals 3–4 months post-ACLr and to explore variations in responses across individuals.

Design: Controlled laboratory study.

Setting: Research laboratory.

Patients or Other Participants: Individuals 109.4 days (18.2 days) post-ACLr (n = 20) and healthy matched controls (CTRL; n = 19).

Intervention: Participants performed double-limb squats in natural (no instruction) and instructed (instruction to evenly distribute weight between limbs) conditions.

Main Outcome Measure(s): Between-limbs and KLS were calculated as the ratio of vertical ground reaction force and knee extensor moment impulse, between surgical (Sx) : matched and nonsurgical (NSx) : matched limbs (ACLr : CTRL), respectively. Intralimb hip/knee (H/K) extensor loading distribution was calculated in Sx : matched limbs.

Results: Limb loading symmetry (natural = 0.86; instructed = 0.93, $P < .001$; effect size = 0.83) and KLS (natural = 0.54; instructed = 0.62, $P = .007$; effect size = 0.67) improved with instruction in the ACLr group with no change in the CTRL group. Hip/knee ratio did not change for either group. Here, *k*-means clustering, considering natural and change (natural-instructed) in LLS, KLS, and H/K ratio, described the response to instruction across 3 clusters: (1) ACLr: n = 3; CTRL: n = 9, were symmetrical in both conditions; (2) ACLr: n = 14, showed some improvement in symmetry, and (3) ACLr: n = 3, only improved LLS.

Conclusions: Average data suggest that weightbearing instruction improved LLS to within 7%, but a 38% knee loading deficit remained, and intralimb compensation did not improve. Data-driven clusters indicate that 3 ACLr participants were similar to CTRLs; 14 improved LLS, KLS, and H/K distribution; and 3 only improved LLS with worsening KLS and H/K.

Key Words: knee extensor moment, intralimb compensation, squat instruction

Key Points

- Instruction to equalize weightbearing is not enough to restore knee loading.
- Baseline or natural loading performance had the greatest influence on data-driven clusters, resulting in 1 large and 2 smaller subgroups that reflect typical and above- and below-average recovery of squat mechanics.
- Differing responses to limb loading instruction across clusters highlight the need for improved and targeted solutions for improving knee loading and reducing intralimb compensations in early recovery after anterior cruciate ligament reconstruction.

Loading strategies that shift mechanical demand away from the surgical knee are well documented in individuals after anterior cruciate ligament reconstruction (ACLr).[1,2] The persistence of loading deficits in the surgical knee contrasts with the primary goal of rehabilitation, which is to restore knee function. Knee extensor moment deficits in the surgical knee during bilateral bodyweight squats have been reported to be between 25% and 38% compared with the contralateral knee and healthy controls (CTRLs) at 3 months post-ACLr.[3,4] This is concerning, as it is expected that individuals with an uncomplicated recovery can successfully perform a bilateral bodyweight squat at 3 months.[5] Longitudinal data indicate that knee extensor loading during a squat does not improve substantially between 3 and 5 months of recovery.[3] Average deficits of 18% have been reported in individuals up to 13 months post-ACLr.[6] Moreover, considerable knee extensor moment deficits observed during squat tasks at 6 months postsurgery are related to deficits observed in the more dynamic stop-jump task.[7] These data suggest that underloading strategies adopted in early recovery persist and can carry over into more dynamic tasks needed for return to sport.

An interlimb compensation that shifts load to the nonsurgical limb during a squat task is a primary contributor of reduced knee extensor moments at 3 months post-ACLr, explaining up to 62% of the variance in knee extensor moment deficits.[3] In previous work in our lab, when compared with uninjured CTRLs, individuals 3 to 4 months post-ACLr underload their surgical limb during bilateral tasks when they are not given specific loading instruction or feedback.[8] On average, asymmetries range between 10% and 24% across bilateral tasks (ie, standing, squat, and sit to stand). However, when instructed to distribute weight, loading symmetry during squatting improved from 15% to 8% on average. This suggests that greater focus on limb loading symmetry (LLS) may be needed in early recovery. While these instructions improve limb loading, it is not known if restoring LLS resolves knee loading deficits in the surgical limb. This is important, as authors of previous work have shown that both interlimb and intralimb compensations underlie knee loading deficits in individuals post-ACLr. The most common intralimb compensation pattern is one that shifts demand within the surgical limb from the knee to the hip.[3,4,6,9,10] In fact, greater contributions from the hip relative to the knee in the surgical limb are primary contributors to knee extensor moment deficits at 5 months post-ACLr.[3] It is not clear if aiming to increase load through the surgical limb during double-limb tasks is sufficient for increasing knee extensor loading and reducing intralimb compensations.

The primary aim of these analyses is to determine if instruction to load limbs symmetrically improves knee loading and reduces intralimb compensations in individuals during early recovery post-ACLr. We hypothesized that surgical knee loading will improve with instruction, and intralimb compensations (hip-to-knee [H/K] ratios) will be reduced.

While comparison of techniques between natural and instructed conditions can provide information regarding the overall influence of instruction, previous data describing squat mechanics in this cohort indicate a wide range in between-limbs deficits. Roos and colleagues described 4 variations in motor strategies used by individuals after ACLr during a squat task in this population.[6] Responses to instruction could also vary across participants, and these variations may be influenced by their baseline mechanics. Data-driven analysis techniques allow for consideration of multiple biomechanical variables together in the description of potential difference in motor patterns and response to instruction. The secondary aim of these analyses is to use a clustering approach to describe how individual responses to instruction vary when considering their natural loading strategy.

METHODS

Participants

Two groups participated: individuals 109.4 days (18.2 days) post-ACLr (n = 20) and healthy matched CTRLs (n = 19). Individuals after ACLr were recruited from 8 physical therapy clinics. To be included in the study, individuals were between ages 14 and 50 years, 0–14 weeks post-ACLr, and currently in physical therapy; they did not have restrictions on weight-bearing after surgery and were cleared to perform squat tasks. Individuals in the CTRL group were matched to postsurgical participants based on age (±2 years), sex, height, and weight. See Table 1 for descriptive information. One CTRL participant was not considered due to movement of tracking markers during data collection.

Instrumentation

Kinematic and ground reaction force (GRF) data were collected synchronously using a marker-based, 14-camera BTS Smart-DX motion capture system and BTS P-6000 force platforms through the BTS Smart-capture software (version 2.8; BTS Bioengineering Corp). Kinematic and GRF data were sampled at 250 and 1000 Hz, respectively.

Table 1. Demographic Characteristics

	ACLr (n = 20)	CTRL (n = 19)
Age, y (mean ± SD)	25.6 ± 10.0	25.8 ± 10.1
Sex, No.	7 M/13 F	7 M/12 F
Height, cm (mean ± SD)	170 ± 8	170 ± 10
Weight, kg (mean ± SD)	71.1 ± 9.39	69.9 ± 9.88
Days post-ACLr (mean ± SD)	110.4 ± 18.4	
Graft type, No.		
BPTB autograft	11	
Hamstring autograft	1	
Quadriceps autograft	2	
Allograft	6	

Abbreviations: ACLr, anterior cruciate ligament reconstruction; CTRL, control; BPTB, bone-patellar, tendon-bone autograft.

Procedures

Testing took place at the University of Southern California, Division of Biokinesiology and Physical Therapy's Human Performance Laboratory. Informed consent was obtained as approved by the Institutional Review Board of the University of Southern California, Health Sciences Campus. Parental consent and youth assent were obtained for participants younger than 18 years. Before testing, participants warmed up on a stationary bike for 5 minutes before placement of reflective markers. The reflective markers (25-mm spheres) were placed on the following anatomical landmarks to define body segments: the L5-S1 junction, bilaterally on the end of second toes, first and fifth metatarsal heads, medial and lateral malleoli, medial and lateral epicondyles of femurs, greater trochanters, posterior superior iliac spines, and iliac crests. Tracking marker clusters were secured to the thighs, shanks, and heel plates of shoes. A static calibration trial was collected with all markers attached. Tracking marker clusters as well as markers on the end of the second toe, iliac crests, posterior superior iliac spines, and the L5-S1 junction remained on the participant throughout the entire testing, while other markers were removed after the static calibration trial.

These data represent a secondary analysis of data collected as a part of a previous study in which nonuse behaviors reflected in limb loading were examined.[8] In the original study, participants performed bilateral tasks under 3 conditions in this order: natural, instructed, and feedback. Kinematic and GRF data were only collected in the natural and instructed conditions, restricting our ability to consider joint kinematics and kinetics across all 3 conditions. For this study, data collected during the squat task in the natural and instructed conditions were analyzed. Briefly, participants performed bilateral tasks in the natural condition first. Starting in a standing position with feet shoulder width apart and arms across their chest, they were instructed to "squat as low as possible without pain or discomfort and come back to standing," repeating 3 consecutive squats. No instructions regarding technique or loading were given. Next, they were instructed to repeat the task but using the following instructions: "Keep your weight evenly distributed on the floor between your legs when you perform the task." Participants were given time to practice the squat task before data collection in the natural condition.

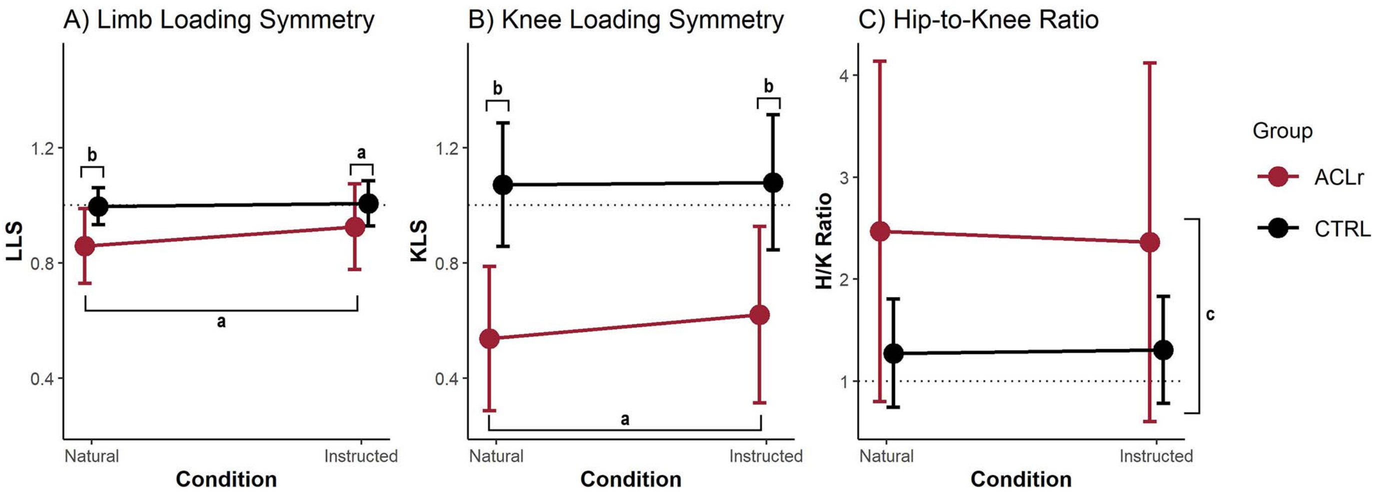

Figure 1. A, Limb loading symmetry, B, knee loading symmetry, and C, hip-to-knee ratio across natural and instructed conditions for individuals after anterior cruciate ligament reconstruction (ACLr) and healthy controls. Symmetry is the ratio of surgical : nonsurgical. [a] Pairwise difference ($P < .05$). [b] Pairwise difference ($P < .001$). [c] Collapsed pairwise difference ($P < .001$).

Data Analysis

Three-dimensional marker coordinates were reconstructed (BTS SMART Tracker) and synchronized with GRF data. Raw coordinate data were low-pass filtered using a fourth-order, zero-lag Butterworth filter with a 6 Hz cutoff frequency (Visual3D; C-motion, Inc). Ankle, knee, and hip kinematics were calculated using a joint coordinate system approach, and 6 degrees of freedom for each segment.[11] Vertical GRF was normalized to body mass ($N \cdot kg^{-1}$). Anthropometric, kinematic, and GRF data were used to calculate sagittal plane net joint moments at the knee and hip, using standard inverse dynamics equations. Moments, reported as internal moments, were normalized to body mass and expressed as $Nm \cdot kg^{-1}$. To characterize loading in each limb and the contributions from the hip and knee extensors during the squat cycle, vertical GRF and hip and knee extensor moment impulse were calculated as the area under the body mass–normalized vertical GRF, hip moment and knee moment versus time curve, respectively. The squat cycle was defined as the time during which the sagittal plane knee moment was negative, indicating an extensor net joint moment. Time to complete the squat cycle was also obtained and reported in seconds.

Within-limbs ratio of H/K extensor moment impulse was calculated for the surgical (ACLr) and matched (CTRL) limbs to characterize the intralimb distribution of hip and knee moments. A H/K ratio of 1 indicates symmetry between hip and knee extensor impulse within the limb, less than 1 indicates larger knee than hip extensor impulse, and greater than 1 indicates larger hip than knee extensor impulse. Limb loading symmetry and knee loading symmetry (KLS) were calculated as a between-limbs ratio of vertical GRF and knee extensor moment impulse, respectively. In the CTRL group, limbs were matched to the ACLr group based on dominance regardless of surgery. The surgical and matched (CTRL) limbs were considered in the numerator and the nonsurgical and matched (CTRL) limbs in the denominator. A ratio of 1 indicates equal distribution of load between limbs or knees, less than 1 indicates loading of the surgical limb/knee was less than that the nonsurgical limb/knee, and greater than 1 indicates loading of the surgical limb/knee was greater than the nonsurgical limb/knee. Data were averaged across 4 trials for analysis.

Statistical Analysis

To determine the effects of condition and group on loading symmetry, separate 2×2 (condition $\times$ group) repeated measure analyses of variance were performed for H/K ratio, LLS, and KLS. The Shapiro-Wilks test was used to evaluate all dependent variables for normality. In the case of a significant interaction, comparisons using independent- or paired-samples *t* tests were conducted between groups and conditions, respectively. Nonparametric Mann-Whitney and Wilcoxon signed ranks tests were used for between-groups and condition comparisons, respectively, for the following variables that were not normally distributed: KLS, H/K ratio, and total time for squat. Cohen *d* effect size (ES) was used to calculate the strength of differences between conditions and groups. Significance level for all tests was set at $\alpha = .05$ (IBM SPSS Statistics; Version 27; IBM Corp).

To describe response patterns across individuals, data were considered in a *k*-means clustering (kmeans function, R 4.1.2) analysis, which is an unsupervised learning method that partitions a dataset into *k* clusters. Clusters represent participants whose combined data are most like each other but distinct from participants assigned to other clusters. Five variables were used as inputs into the cluster analysis. Limb loading symmetry and KLS during the natural condition were considered indications of baseline loading strategies. Changes (instructed-natural) between conditions in KLS, LLS, and surgical limb H/K ratio were included to reflect individuals' responses to instruction. The optimal number of clusters that best defines the response patterns of the participants was determined using the silhouette method. This method considers the average distance between participants assigned to the same cluster to those assigned to the other clusters in solutions for different numbers of clusters. The solution with the highest average silhouette width represents the optimal number of clusters to describe the response patterns in this dataset.[12] The relative importance of each variable in the determination of clustering was identified using a random forest algorithm (randomForest package, R 4.1.2). Cluster assignments were used as the outcome variable, and variable importance was obtained. Mean decrease in accuracy (MDA) is quantified

Table 2. Between-Groups and Condition Comparisons (Mean ± SD)

	ACLr		CTRL	
	Natural	Instructed	Natural	Instructed
LLS	0.859 ± 0.130[a,c]	0.926 ± 0.148[b]	0.997 ± 0.064	1.007 ± 0.078
KLS	0.538 ± 0.250[a,c]	0.621 ± 0.307[c]	1.071 ± 0.215	1.079 ± 0.235
Knee extensor moment impulse (Nm·s/kg)				
Surgical : matched	0.683 ± 0.270[a,b,d]	0.809 ± 0.366[d]	0.856 ± 0.260	0.856 ± 0.280
Nonsurgical : matched	1.364 ± 0.488[c]	1.415 ± 0.649[b]	0.828 ± 0.299	0.830 ± 0.319
H/K extensor ratio[e]	2.469 ± 1.668	2.363 ± 1.758	1.274 ± 0.531	1.305 ± 0.524
Total time (s)	1.879 ± 0.421[a,b]	2.174 ± 0.671[b]	1.472 ± 0.262	1.529 ± 0.341

Abbreviations: ACLr, anterior cruciate ligament reconstruction; CTRL, control; H/K, hip to knee; KSL, knee extensor loading symmetry; LLS, limb loading symmetry.
[a] Indicates significantly different from the instructed condition ($P < .01$).
[b] Indicates significantly different from CTRL ($P < .05$).
[c] Indicates significantly different from CTRL ($P < .001$).
[d] Indicates significantly different from the nonsurgical limb ($P < .001$).
[e] Indicates significantly different from CTRL when collapsed across condition ($P < .001$).

for each variable, for which higher values are indicative of a greater variable importance.

RESULTS

A significant condition × group interaction was observed for KLS ($P = .038$). Post hoc testing indicated KLS increased from natural to instructed conditions in the ACLr group (0.54 to 0.62; $P = .007$; ES = −0.673), and no significant difference was found between conditions for the CTRL group ($P = .702$; Figure 1, Table 2). The ACLr group had lower KLS than the CTRL group in both the natural (0.54 versus 1.07; $P < .001$; ES = −2.281) and instructed (0.62 versus 1.08; $P < .001$; ES = −1.675) conditions.

A significant condition × group interaction was observed for LLS ($P = .011$). Post hoc testing indicated LLS increased from the natural to the instructed condition in the ACLr group (from 0.86 to 0.93; $P < .001$; ES = −0.825), with no significant difference between conditions for the CTRL group ($P = .307$; Figure 1, Table 2). Compared with the CTRL group, LLS was lower in the ACLr group in both the natural (0.86 versus 0.99; $P < .001$; ES = −1.336) and instructed (0.93 versus 1.01; $P = .039$; ES = −0.681) conditions.

A significant main effect of group was noted for H/K ratio ($P = .009$; Figure 1, Table 2). When collapsed across condition, surgical limb H/K ratio in the ACLr group was significantly greater than the matched limb H/K ratio in the CTRL group (2.42 versus 1.29; $P < .001$; ES = 0.89). No significant interaction between group and condition was observed.

A significant condition × group interaction was found for time to complete the squat. Total squat time was greater in the ACLr group in both conditions than CTRLs, and it took longer to complete the squat during the instructed condition than the natural condition for individuals post-ACLr (Table 2). No difference in squat time was observed between conditions in the CTRL group.

Based on the results of the silhouette method, 3 clusters were chosen, as they resulted in the highest average silhouette width. All individuals in the CTRL group (n = 19) were classified into Cluster 3 along with 3 from the ACLr group. Fourteen individuals from the ACLr group were classified in Cluster 2, and 3 were classified in Cluster 1. The primary variable contributing to the distribution across clusters (Figure 2) was natural KLS (MDA = 26.9) followed by change in H/K ratio and natural LLS (14.9 and 13.1, respectively). Individual and average data for LLS, KLS, and H/K ratio are plotted in the natural and instructed conditions for each cluster to visualize differences across clusters (Figure 3), and descriptive data (mean ± SD and difference between conditions) are presented in Table 3.

DISCUSSION

In this study, we build on previous work in which the nature of loading behaviors in individuals 3–4 months post-ACLr were examined; and individuals were found to improve limb loading asymmetries when they were given instructions to load symmetrically.[8] As reflected in the previous analyses of these data, on average, LLS improved with instruction from 0.86 to 0.93. When we examined KLS in this same group, we found that, on average, knee loading deficits improved approximately 8%, supporting our primary hypothesis. However, a 38% deficit in surgical knee extensor moments remained.

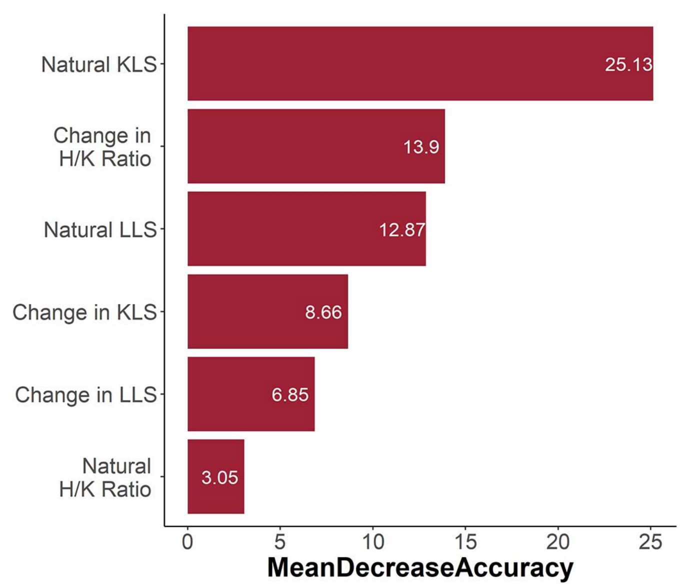

Figure 2. Variable importance in determining cluster assignments. Each bar represents the variables included in the *k*-means cluster analysis. Larger mean decrease in accuracy explains variables that contributed most to the determination of cluster assignments.

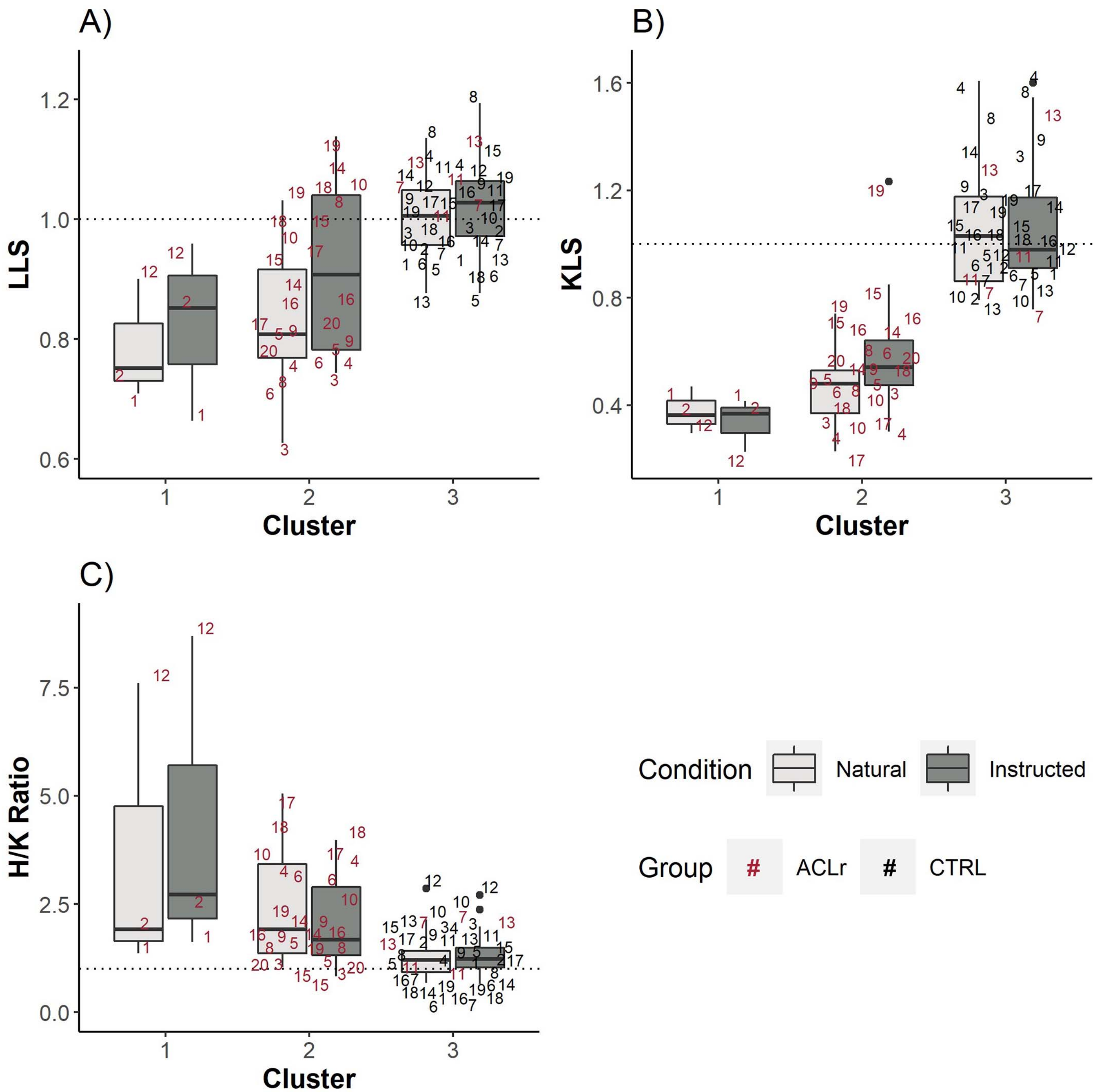

Figure 3. A, Limb loading symmetry, B, knee loading symmetry, and C, hip-to-knee ratio in each cluster. The light gray boxplots represent the natural condition, and the dark gray boxplots represent the instructed condition. Individual data points are plotted as participant IDs. Red numbers represent the anterior cruciate ligament reconstruction (ACLr) group, and black numbers represent the control (CTRL) group.

Large knee extensor moment deficits in bilateral squat tasks have been reported in previous literature during early recovery and beyond the completion of rehabilitation.[3,4,6,7] Furthermore, knee extensor moment deficits are observed in the presence of symmetrical limb loading during squatting in individuals 6 months to over 5 years after surgery.[6,13,14] When considering average data, it appears that improvements in limb loading translated to increases in surgical knee extensor moments, but contrary to our hypothesis, it did not translate to changes in the H/K distribution. Instructions to equalize weight distribution between limbs did not result in changes in H/K ratio in either group. On average, the H/K ratio was nearly 2 times greater in the ACLr surgical limb than the matched CTRL limb. This indicates that individuals in the ACLr group used a pattern that relied more heavily on the hip versus knee extensors than CTRLs. The persistence of this strategy in the instructed condition likely underlies the limited improvements in knee extensor loading with instruction. This is of concern, as the instructions provided mimic those given during physical therapy in early recovery after ACLr. These data suggest that, in addition to instructions to restore interlimb weight distribution, more specific instructions or feedback aimed at redistribution loading within the limb may be needed to improve knee extensor loading.

Table 3. Mean ± SD for Each Cluster

	LLS			KLS			H/K		
	Natural	Instructed	Difference	Natural	Instructed	Difference	Natural	Instructed	Difference
Cluster 1									
ACLr (n = 3)	0.787 ± 0.100	0.825 ± 0.145	0.038 ± 0.075	0.377 ± 0.087	0.337 ± 0.10	−0.040 ± 0.039	3.628 ± 3.454	4.345 ± 3.810	0.716 ± 0.423
Cluster 2									
ACLr (n = 14)	0.834 ± 0.113	0.915 ± 0.142	0.080 ± 0.088	0.476 ± 0.146	0.590 ± 0.233	0.114 ± 0.123	2.435 ± 1.289	2.110 ± 1.064	−0.322 ± 0.321
Cluster 3									
All (n = 22)	1.004 ± 0.062	1.017 ± 0.079	0.013 ± 0.043	1.060 ± 0.218	1.075 ± 0.244	0.015 ± 0.092	1.300 ± 0.511	1.338 ± 0.511	0.038 ± 0.147
ACLr (n = 3)	1.048 ± 0.035	1.079 ± 0.059	0.031 ± 0.044	0.989 ± 0.278	1.046 ± 0.361	0.058 ± 0.109	1.467 ± 0.404	1.544 ± 0.445	0.077 ± 0.113
CTRL (n = 19)	0.997 ± 0.064	1.007 ± 0.078	0.011 ± 0.044	1.071 ± 0.215	1.079 ± 0.234	0.008 ± 0.090	1.274 ± 0.531	1.305 ± 0.524	0.032 ± 0.153

Abbreviations: ACLr, anterior cruciate ligament reconstruction; CTRL, control; H/K, hip to knee; KSL, knee loading symmetry; LLS, limb loading symmetry.

When individual data were considered, it was clear that not all participants in this cohort behaved the same, making it difficult to make generalized conclusions about the average data. Further consideration of these data using unsupervised clustering analyses provided more insight into how individuals respond to instructions to evenly distribute loads between limbs. Changes in LLS, KLS, and H/K ratio from the natural to the instructed condition were considered along with individuals' baseline status by including data from the natural squat condition. Mathematically, the silhouette method confirms that data describing 3 clusters provided the best distinction between clusters. Cluster 3 included all the participants in the CTRL group (n = 19). The largest number of participants from the ACLr group was assigned to Cluster 2 (n = 14), with n = 3 assigned to both Clusters 3 and 1. When considering the characteristics of Clusters 3 and 1, it appears that the data reveal small subgroups of individuals who exhibit levels of recovery that would be considered above and below average, respectively, for this point in time after surgery.

When considering the variables that contributed the most to cluster assignment, we found that 2 of the 3 variables with the highest MDA represented baseline deficits (Figure 2). The primary contributor to cluster assignment was KLS in the natural condition, with natural LLS having the third highest MDA. Average KLS and LLS for Cluster 3 were relatively symmetrical with ratios close to 1 (Figure 3A and B, Table 3). The inclusion of 3 individuals from the ACLr group along with all CTRL participants in Cluster 3 suggests that these individuals behaved like CTRLs. In contrast, Clusters 2 represented individuals with lower ratios in natural KLS (0.48) and LLS (0.83; Figure 3A and B, Table 3). While Cluster 1 included only 3 individuals, the average natural KLS and LLS of 0.38 and 0.79, respectively, suggest that their baseline performance was the most impaired (Figure 3A and B, Table 3).

The only variable reflecting a change between baseline (natural) and instructed conditions that made a substantial contribution to cluster assignment was change in H/K ratio. It was the second most influential variable contributing to cluster assignment (Figure 2). At baseline, the average H/K ratio was lowest in Cluster 3 (1.3), indicating a more equal distribution between the hip and knee with larger average ratios in Clusters 1 (2.43) and 2 (3.63; Figure 3C, Table 3). Larger differences in H/K ratio were observed in Clusters 1 and 2, with the direction of change being different between clusters. All 3 individuals in Cluster 1 exhibited an increase in the contribution from the hip relative to the knee in response to instructions. This differentiated them from individuals assigned to Cluster 2, who appeared to have a decrease or no change in the H/K following instruction (Figure 3C, Table 3).

Several limitations of this study should be addressed in future work. From a clinical perspective, it is not known if the persistence of this compensation is necessary in this cohort or if it is learned. It is possible that increasing limb loading increases surgical knee demands that exceed one's ability to accommodate them. All tasks were performed to a self-selected depth and without pain of discomfort; however, patient-reported function and psychosocial or neurological variables were not considered in this assessment. Future work is needed to determine factors that contribute to adoption of this intralimb compensation and mechanisms to reverse it. While the distribution of individuals in the ACLr group across clusters separated those with higher and lower levels of performance from the average cohort, the sample size is too small to extrapolate these findings across this population. A larger sample size is needed to better define this distribution and the variables that define slower progress. This information will be critical for informing intervention approaches.

These analyses provide important context to the issues around persistent knee extensor loading deficits after ACLr. In general, using instruction to keep weight evenly distributed between legs during a squat task can improve LLS and KLS in individuals 3–4 months post-ACLr; however, improvements in knee loading are modest, and an average deficit of 38% remains with no improvement in intralimb distribution. Greater consideration of individual data allows clinicians to appreciate that not all patients respond the same. Data-driven cluster analysis that mathematically defines differences in motor strategies indicates that natural squat strategies (baseline performance) may factor heavily into how individuals respond. The variation in responses across the 3 variables was chosen to characterize squat mechanics. The individuals plotted in Figure 3 underscore the complexity of compensations used to underload the knee after ACLr. The inclusion of participant-specific surgical and strength data provides additional clinical measures to help contextualize data (see Supplemental Appendix), allowing clinicians more insight into potential patterns observed in their practice. With multiple degrees of freedom in the system, individuals can redistribute demands aways from the surgical knee with subtle adjustments to the trunk, hip, knee and ankle flexion, center of pressure position, and transverse and frontal plane pelvic and hip positions.[9,15–17] It is not surprising that, for some people, compensations persist long term and across different double-limb tasks. Awareness of these issues and identification of individuals who are recovering slower than average may allow for directed rehabilitation strategies.

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SUPPLEMENTAL MATERIAL

Supplemental Appendix. Individual descriptive data and results.

Address correspondence to Susan Sigward, PT, ATC, PhD, Human Performance Laboratory, Division of Biokinesiology and Physical Therapy, University of Southern California, 1540 Alcazar St, CHP 155, Los Angeles, CA 90089-9006. Address email to sigward@usc.edu.