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Reliability of 3-Dimensional Measures of Single-Leg Cross Drop Landing Across 3 Different Institutions

Implications for Multicenter Biomechanical and Epidemiological Research on ACL Injury Prevention

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Investigation performed at The Human Performance Laboratory and Sports Medicine Biodynamics Center at Cincinnati Children's Hospital Medical Center, Cincinnati, Ohio, USA

Background: Anterior cruciate ligament (ACL) injuries are physically and financially devastating but affect a relatively small percentage of the population. Prospective identification of risk factors for ACL injury necessitates a large sample size; therefore, study of this injury would benefit from a multicenter approach.

Purpose: To determine the reliability of kinematic and kinetic measures of a single-leg cross drop task across 3 institutions.

Study Design: Controlled laboratory study.

Methods: Twenty-five female high school volleyball players participated in this study. Three-dimensional motion data of each participant performing the single-leg cross drop were collected at 3 institutions over a period of 4 weeks. Coefficients of multiple correlation were calculated to assess the reliability of kinematic and kinetic measures during the landing phase of the movement.

Results: Between-centers reliability for kinematic waveforms in the frontal and sagittal planes was good, but moderate in the transverse plane. Between-centers reliability for kinetic waveforms was good in the sagittal, frontal, and transverse planes.

Conclusion: Based on these findings, the single-leg cross drop task has moderate to good reliability of kinematic and kinetic measures across institutions after implementation of a standardized testing protocol.

Clinical Relevance: Multicenter collaborations can increase study numbers and generalize results, which is beneficial for studies of relatively rare phenomena, such as ACL injury. An important step is to determine the reliability of risk assessments across institutions before a multicenter collaboration can be initiated.

Keywords: multicenter; biomechanics; anterior cruciate ligament; epidemiology

Sports-related injuries to the anterior cruciate ligament (ACL) affect approximately 1% to 3% of the athletic population on average^{10,23,24}; however, when they do occur, these injuries are devastating physically,²¹ psychologically,²⁰ and economically.^{2,8,10,18} Investigations on relatively rare

phenomena such as this require large-scale studies to adequately power results. Because of the low incidence rate for ACL injury, the number of subjects needed to prospectively study the noncontact ACL injury phenomena total in the hundreds, if not thousands. Furthermore, data collection and risk assessment of relatively rare events, like ACL injuries, typically require costly technologies and trained personnel to reliably collect prospective data from a large subject pool, which is challenging for even an

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adequately staffed research laboratory. Multicenter collaborative studies allow researchers to share responsibilities and resources while vastly increasing the available subject pool. They can also increase the generalizability of prospective risk assessment for ACL injury by improving the ability to include additional populations of interest into prospective studies. Moreover, increased subject pools allow for the opportunity to achieve adequate statistical power through an increased sample size. Thus, use of a multicenter approach is likely the most feasible method to execute prospective, coupled biomechanical-epidemiological studies.

Specific risk factors for ACL injury include increased dynamic knee abduction (caused by increased hip internal rotation and/or adduction, which contribute to knee joint movement toward the midline), decreased knee flexion, elevated ground reaction force during landing, and asymmetrical landing patterns.¹³ In general, these factors are observed in subjects performing sports-related tasks, such as landing from a jump,²² which directly affects knee alignment and load transmission through the knee.^{12,14,25} Furthermore, 2-dimensional video analyses have indicated that female athletes with a noncontact ACL injury had greater lateral trunk flexion along with increased peak knee abduction during landing compared with both female and male control athletes.¹⁵ With regard to trunk motion, there is a link between lateral trunk flexion and ACL injury whereby aberrant lateral trunk motion perturbs the center of mass and directly affects proximal knee loading.^{17,30} While many risk factor studies have effectively included analyses of landing maneuvers, including drop vertical jumps^{4,13} and single-leg jump landings,⁵ these maneuvers perhaps may not adequately challenge trunk control for assessment of deficits that influence lower extremity biomechanics.

Given the extensive negative health consequences of ACL injury and the low incidence rate of these injuries, collaboration between multiple research laboratories is necessary to increase sample size and enhance generalizability. An important step in the establishment of such an approach is to determine whether the tasks can be reliably studied between institutions. The purpose of this project was to determine the reliability and consistency of kinematic and kinetic measures collected during a single-leg cross drop task (SCD) using 3-dimensional motion analysis across 3 different institutions.

METHODS

Participants

Twenty-five female junior varsity and varsity level high school volleyball players participated in this study. Institutional review board approval was received and informed consent was obtained from subjects prior to testing. The participants were transported to 3 different testing sites on separate dates over a 4-week period. All participants were tested at each site before moving to the next site. Issues in model template and 3-dimensional motion tracking resulted in only 12 participants having complete data sets (mean [SD] age, 15.34 [0.6] years [standard error of mean, SEM, 0.125 years]; mean [SD] height, 1.69 [0.04] m [SEM, 0.0083 m]; mean [SD] weight, 58.36 [6.0] kg [SEM, 1.25 kg]) and being included in the final analysis.

Procedures

Three-dimensional motion data were collected using each site's own passive optical motion capture camera system and triaxial force plates. Motion data at the first testing site were collected using a 10-camera motion capture system (Motion Analysis Corp) synced with embedded AMTI force plates (AMTI) collected at 1200 Hz. Motion data at the second testing site were collected at 200 Hz using an 18-camera motion capture system (Motion Analysis Corp) and Bertec split-belt treadmill (Bertec Co) collected at 1000 Hz. Motion data at the remaining testing site were collected at 240 Hz using an 8-camera motion capture system (Vicon) and embedded Bertec force plates (Bertec Co) collected at 1200 Hz. To reproduce a situation most realistic to a multicenter collaboration, each testing site utilized its own research staff for motion capture data collection. At each site, a research assistant instrumented participants with 43 retroreflective markers in a modified Helen-Hayes arrangement (Figure 1A). Anatomic markers were placed on the spinous process of the seventh cervical vertebra, sternal notch, and sacrum. Markers were placed bilaterally on the acromioclavicular joint, lateral epicondyle of the elbow, midwrist, anterior superior iliac spine, greater trochanter, medial and lateral femoral condyles, and medial and lateral malleoli. Additional tracking markers were placed to the left of the sacrum and bilaterally on the upper arms, midhigh, tibial tubercle, and distal and

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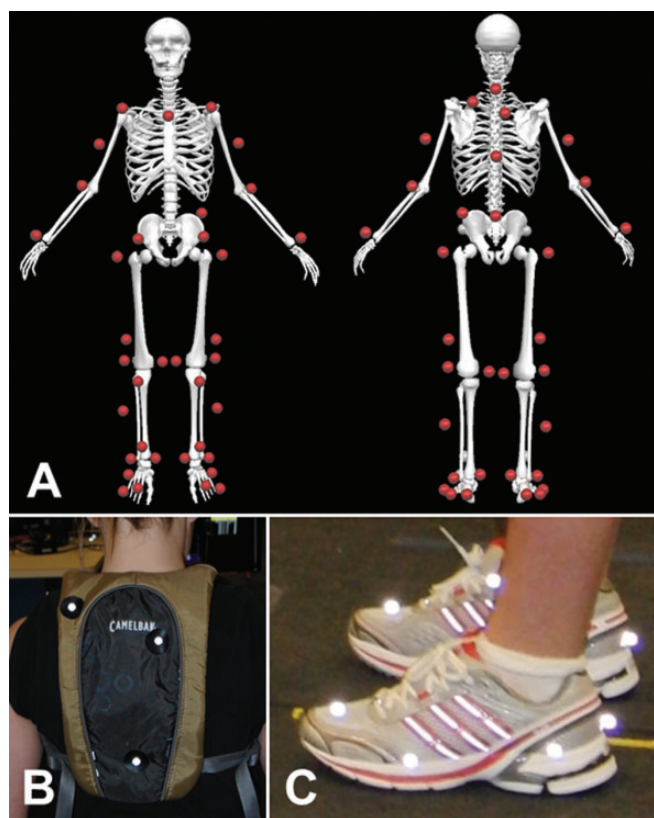


Figure 1. Depiction of the marker placement and accessories used. (A) Front and back views of the marker placement. (B) Backpack showing 3 noncollinearly placed markers. (C) Standardized shoe (Supernova Glide 2; Adidas) showing the 4 embedded markers (heel, dorsal surface of the midfoot, lateral foot, and toe).

lateral aspects of the shank. Participants wore a standardized shoe that was sized according to the subject's self-selected shoe size and shared among all 3 sites (Supernova Glide 2; Adidas), with markers embedded at the heel, the dorsal surface of the midfoot, lateral foot (fifth metatarsal), and toe (between the second and third metatarsal) (Figure 1C). Participants also wore a small backpack outfitted with 3 noncollinearly placed markers to track trunk motion (Figure 1B). The backpack was fit tightly to the contour of each participant's back and was necessary because research assistants did not have direct access to the skin to place markers. A static trial was conducted, and the participant was instructed to stand in a neutral position with foot direction standardized to the laboratory's coordinate system.

Single-Leg Cross Drop

The SCD is a novel task by which the roles of both the trunk and lower extremities in ACL injury may be uniquely quantified. A refined theoretical model of the ACL injury mechanism proposed the combined effect of lateral trunk flexion, knee abduction load, hip musculature torque, and ground reaction force on risk for injury.¹¹ Spurred by this theoretical model, the SCD was developed to reproduce the effect lateral trunk flexion may have on the knee joint in a controlled laboratory environment. The SCD generates lateral momentum of the center of mass that perturbs the trunk on landing and simultaneously challenges the lower extremity and hip musculature to maintain alignment of the knee over the stance foot. This movement is hypothesized to magnify the neuromuscular strategies that increase external knee joint loads and may serve an important role in identifying multiplanar deficits in trunk proprioception and control to accurately predict primary ACL injury.^{30,31}

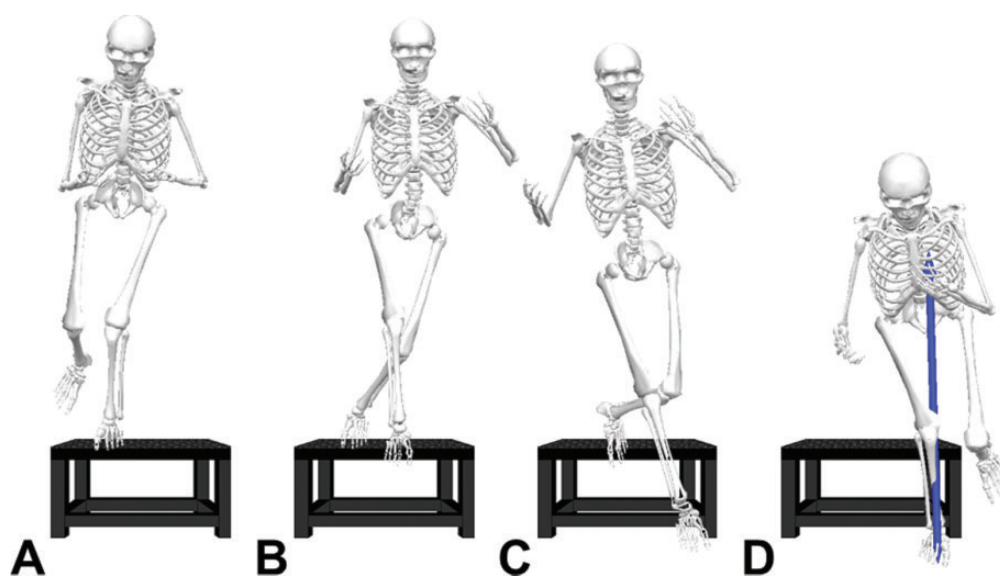


Figure 2. Illustration of the single-leg cross drop task: (A) the initial position, (B) take-off from the box, (C) immediately before initial contact, and (D) at the end of the landing phase.

TABLE 1
Peak Values and Range of Motion Recorded for Kinematic and Kinetic Variables During a
Single-Leg Cross Drop Landing Maneuver Performed at Each Testing Center

	Left Leg						Right Leg					
	Peak			Range of Motion			Peak			Range of Motion		
	I	II	III	I	II	III	I	II	III	I	II	III
Kinematic, deg												
Hip flexion	58.6	53.2	51.7	32.8	28.3	29.0	59.2	51.7	53.2	33.0	26.7	31.2
Hip adduction	9.9	8.0	8.7	14.8	13.8	15.0	14.2	10.2	14.0	18.7	16.9	18.3
Hip internal	-4.5	-6.0	-5.8	13.2	14.7	11.7	-5.7	-6.7	-6.7	14.0	15.1	16.2
Knee flexion	65.9	61.3	66.2	52.1	46.9	50.4	68.2	65.5	65.3	54.8	49.7	51.0
Knee abduction	9.0	8.9	8.3	9.1	10.5	9.9	10.6	9.2	12.4	9.7	10.9	12.8
Knee internal	6.8	9.3	9.1	14.7	16.5	16.9	2.0	9.5	8.9	14.0	15.4	15.4
Ankle dorsiflexion	20.9	19.0	20.1	53.7	52.4	50.4	22.3	25.0	20.6	55.1	52.6	50.0
Ankle eversion	16.7	17.8	18.5	13.1	13.2	14.2	15.5	15.4	17.0	12.8	13.3	14.1
Trunk flexion	36.1	36.1	28.4	22.4	13.2	16.9	35.7	34.9	31.3	20.1	13.1	17.7
Trunk lateral flexion	9.3	15.5	8.6	9.6	22.0	7.9	6.4	11.3	8.4	11.2	18.7	8.0
Kinetic, N·m/kg												
Hip flexion	103.9	80.9	91.7	109.3	123.1	140.5	105.3	83.9	80.5	110.3	136.2	139.9
Hip adduction	90.6	90.9	85.9	92.2	89.0	91.6	104.3	92.0	95.1	101.7	92.4	102.1
Hip internal	43.8	48.8	37.9	45.8	45.2	39.7	47.6	40.3	49.6	46.4	56.2	42.5
Knee flexion	134.2	141.2	144.9	136.3	139.5	148.4	129.3	145.3	138.8	135.1	126.8	148.7
Knee abduction	10.3	5.4	10.4	41.3	36.5	43.3	6.7	15.7	11.3	43.4	43.8	45.3
Knee internal	1.5	8.8	2.9	30.9	29.3	33.2	1.2	3.5	5.4	34.6	28.7	32.6
Ankle dorsiflexion	121.6	119.2	120.8	117.6	122.9	121.6	126.6	118.9	114.6	120.1	145.3	118.2
Ankle eversion	40.2	40.4	47.9	45.0	51.2	47.7	36.9	43.9	40.4	44.9	42.4	47.0

Participants performed a total of 3 SCD maneuvers on each side from a 31-cm box (Figure 2). The SCD was performed by balancing on 1 foot and then hopping forward and medially off the box. While in the air, the subject crossed the foot that she would ultimately land on in front of the “balancing” foot. For example, to perform an SCD on the right side, participants were instructed to align their left foot on a piece of tape that was affixed to the right top of the box and to balance on her left leg (Figure 2A). Once in this position, the participant hopped off the box, simultaneously crossing over with the right foot (Figure 2B) and landing on the right foot in the middle of the force plate, holding the landing for a minimum of 2 seconds (Figure 2, C and D). Trials were repeated if participants stepped off the box instead of hopping, turned their entire body in the direction they were hopping instead of remaining parallel to the box, or were unable to hold the landing on contact with the force plate.

Analysis

Marker trajectories and force data were both filtered using a low-pass fourth-order Butterworth filter at a cutoff frequency of 12 Hz. Lower extremity Cardan angles and moments were calculated using Visual3D (C-Motion, Inc) pipeline scripts and exported for further analysis. Participants who had incomplete marker data (“critical” marker gaps of 100 ms or greater) resulting in less than 2 complete trials at each site were not included in the final analysis. For each subject included in the analysis, kinematic and

kinetic waveforms were calculated during the landing phase of each of the 2 accepted SCD trials at each individual center using custom Matlab scripts (Mathworks). The landing phase was defined as the time from initial contact with the force plate (vertical ground reaction force >20 N) to 500 ms after the initial contact. These waveforms were then normalized to 101 data points, and from these data peak values were determined and averaged between the 2 successful trials. The peak values were then used to calculate the range of motion (ROM) that occurred from initial ground contact through the point where minimum center of gravity was achieved.

Peak values, ROMs, and waveforms were used to calculate reliability and total error individually for the right and left legs. Coefficients of multiple correlation (CMC) were used to calculate kinematic and kinetic waveform reliability during the landing phase of the SCD.¹⁹ Standard errors were also calculated between sessions and were reported in degrees for kinematic variables and newton-meters per kilogram (N·m/kg) for kinetic variables.¹⁶ All statistical analyses were performed using custom Matlab scripts.

RESULTS

Peak values and ROMs for kinematics and kinetics observed at the hip, knee, ankle, and trunk at each center during SCD are documented in Table 1. Between-centers reliability for all kinematic waveforms in the frontal and sagittal planes was good, with all CMC values exceeding

TABLE 2
Between-Center CMC and Total Error Values for Kinematic and Kinetic Variables
Calculated for Both the Left and Right Limb at All Combinations of Testing Centers^a

	All 3 Centers		I vs II		I vs III		II vs III	
	CMC	Standard Error	CMC	Standard Error	CMC	Standard Error	CMC	Standard Error
<i>Left leg</i>								
Kinematic, deg								
Hip flexion	0.930	9.18	0.885	4.90	0.895	11.03	0.905	11.61
Hip adduction	0.772	4.56	0.856	4.54	0.695	5.69	0.836	3.46
Hip internal	0.647	4.59	0.707	4.73	0.788	4.33	0.668	4.71
Knee flexion	0.956	5.36	0.929	4.11	0.936	6.29	0.926	5.70
Knee abduction	0.764	2.51	0.695	2.88	0.728	2.73	0.736	1.93
Knee internal	0.775	3.24	0.687	3.45	0.614	2.62	0.674	3.64
Ankle dorsiflexion	0.972	3.05	0.976	2.21	0.949	3.86	0.965	3.07
Ankle eversion	0.748	1.89	0.722	1.81	0.733	2.31	0.777	1.56
Trunk flexion	0.963	6.68	0.998	3.32	0.800	6.35	0.830	6.15
Trunk lateral flexion	0.382	3.38	<0.000	2.88	0.982	2.45	<0.000	2.91
Kinetic, N-m/kg								
Hip flexion	0.882	0.43	0.798	0.35	0.825	0.45	0.860	0.50
Hip adduction	0.831	0.32	0.808	0.20	0.752	0.35	0.790	0.42
Hip internal	0.823	0.13	0.806	0.08	0.783	0.15	0.673	0.17
Knee flexion	0.927	0.34	0.883	0.37	0.871	0.35	0.930	0.29
Knee abduction	0.710	0.16	0.596	0.16	0.668	0.15	0.470	0.18
Knee internal	0.743	0.08	0.517	0.07	0.607	0.08	0.617	0.08
Ankle dorsiflexion	0.918	0.16	0.868	0.16	0.855	0.17	0.888	0.16
Ankle eversion	0.913	0.11	0.904	0.10	0.851	0.09	0.854	0.12
<i>Right leg</i>								
Kinematic, deg								
Hip flexion	0.925	9.50	0.835	3.34	0.903	12.26	0.870	12.89
Hip adduction	0.829	4.71	0.866	3.79	0.749	5.79	0.692	4.56
Hip internal	0.781	3.67	0.691	3.34	0.734	4.30	0.752	3.36
Knee flexion	0.927	9.33	0.923	9.99	0.888	7.45	0.940	10.55
Knee abduction	0.790	2.58	0.718	2.77	0.824	2.55	0.710	2.43
Knee internal	0.623	9.13	0.669	11.49	0.597	3.36	0.698	12.54
Ankle dorsiflexion	0.951	9.46	0.982	12.14	0.947	4.58	0.967	11.64
Ankle eversion	0.793	3.65	0.653	4.44	0.736	1.92	0.752	4.59
Trunk flexion	0.977	6.98	0.997	3.56	0.886	6.58	0.908	6.44
Trunk lateral flexion	<0.000	3.19	<0.000	2.58	<0.000	2.10	0.769	3.06
Kinetic, N-m/kg								
Hip flexion	0.786	0.35	0.744	0.27	0.781	0.36	0.844	0.43
Hip adduction	0.871	0.42	0.776	0.33	0.793	0.41	0.838	0.52
Hip internal	0.878	0.19	0.871	0.19	0.834	0.17	0.837	0.20
Knee flexion	0.924	0.36	0.869	0.41	0.878	0.29	0.899	0.38
Knee abduction	0.720	0.12	0.683	0.13	0.590	0.10	0.575	0.14
Knee internal	0.771	0.04	0.643	0.03	0.840	0.05	0.770	0.05
Ankle dorsiflexion	0.888	0.30	0.845	0.33	0.813	0.25	0.846	0.33
Ankle eversion	0.892	0.16	0.749	0.17	0.848	0.11	0.757	0.20

^aCMC, coefficients of multiple correlation.

0.75 (Table 2 and Figure 3), except for lateral trunk flexion, which had poor reliability. The hip, knee, and ankle joint kinematics demonstrated greater waveform reliability in the sagittal plane (CMC, 0.93-0.97) than in the frontal plane (CMC, 0.75-0.83); trunk kinematics also demonstrated much greater reliability in the sagittal plane (CMC, 0.80-0.99) than the frontal plane. Transverse plane kinematics were the least reliable waveform degree of freedom at the hip and knee, with CMC values ranging between 0.62 and 0.78. In most cases, standard errors between centers in the sagittal plane were greater (hip, 9.3°; knee,

7.3°; ankle, 6.3°) than the frontal (hip, 4.6°; knee, 2.5°; ankle, 2.8°) and transverse planes (hip, 4.1°; knee, 6.2°) at each joint.

Between-centers reliability for kinetic waveforms was also highly reliable in the sagittal plane, with all CMC values exceeding 0.79 (Table 2 and Figure 4). Kinetics in the transverse plane also expressed moderate to good between-centers reliability, with CMCs greater than 0.72. Frontal plane moment waveforms were reliable between all 3 centers (CMC >0.71), but knee abduction moment reliability was lower between some individual

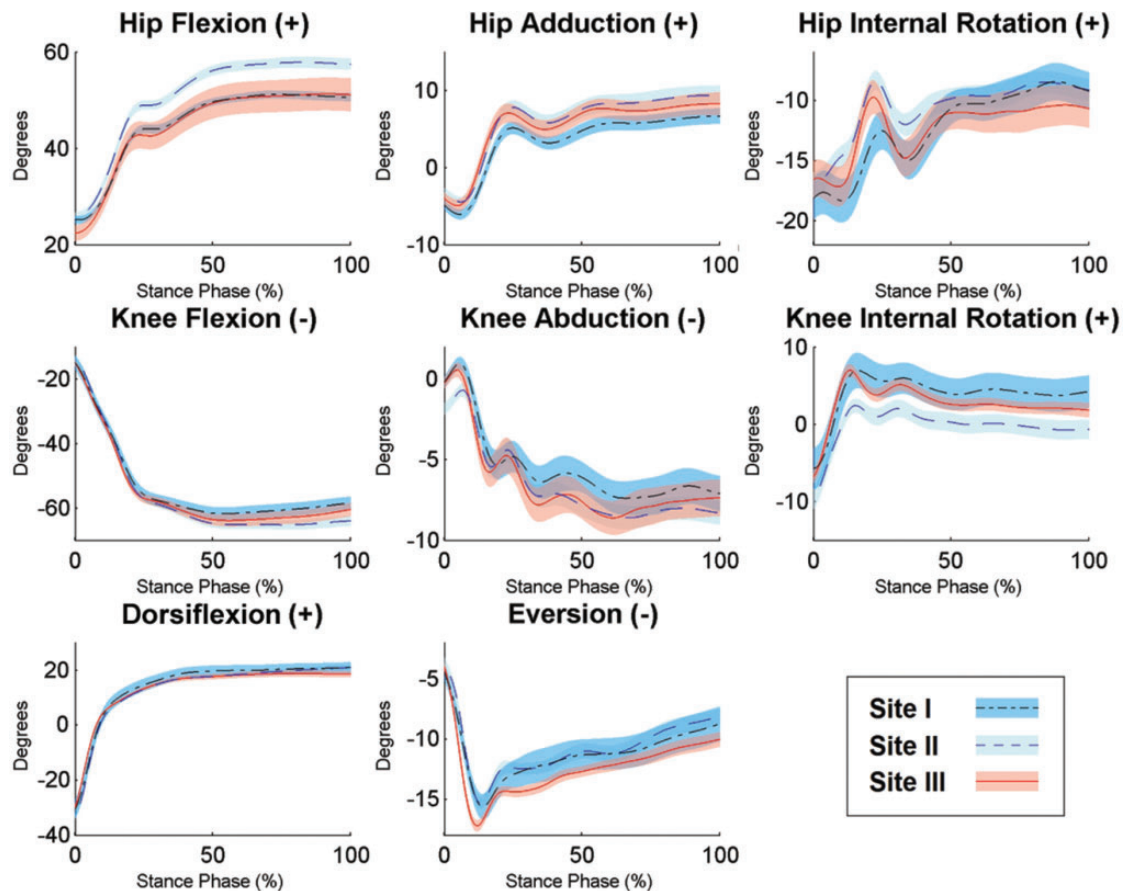


Figure 3. Mean kinematics for both sides of the single-leg cross drop landing from 0 to 500 ms after initial contact with the force plate, normalized to 101 data points, for all subjects at each of the 3 institutions. The shaded area represents standard error of the mean.

center combinations (minimum CMC, 0.52). As with kinematics, kinetics in the transverse plane expressed the greatest side-to-side differences in waveform reliability. Standard errors for kinetics between centers ranged from 0.04 to 0.43 N·m/kg. The largest standard errors corresponded with the plane of motion that expressed the largest peak moment, which were sagittal plane moments at all 3 joints and frontal plane moments at the hip.

DISCUSSION

Before pursuing a multicenter study designed to investigate relatively rare phenomena such as ACL injury, the between-centers reliability of screening tasks must be calculated and documented. Factors that potentially increase variability across institutions should also be identified, and proper steps should be taken to minimize these confounders. Furthermore, evaluation of tasks that include trunk motion as a part of risk factor assessment is an important feature to include when attempting to identify individuals at risk for ACL injury. The purpose of this study was to observe the reliability of kinematic and kinetic measures during the SCD across 3 institutions. Overall, the SCD task

expressed good to excellent kinematic waveform reliability between centers in the sagittal plane. Transverse and frontal plane kinematics were less reliable, with transverse plane motions being slightly less reliable than frontal plane motions. These results indicate that the SCD has good waveform reliability in the sagittal plane and moderate to good reliability in the frontal and transverse planes in adolescent female athletes when the task is implemented across institutions using standardized testing protocols and data analyses.

Reliability of kinematics of the SCD task in the sagittal plane was the greatest at the ankle and lowest at the hip, whereby kinetics was greatest at the knee and lowest at the hip. Although this pattern was also present in previous between-session reliability analyses for a drop vertical jump task performed from the same height, the magnitude of difference in CMCs between joints was smaller than in the present study.³ There were no discernible trends in reliability between joints for the frontal and transverse planes. Kinematics in the sagittal plane showed the greatest variability in angle during the SCD task, which could explain increased reliability in this plane, as small variations in larger movements are less likely to have a negative impact on reliability. Although sagittal plane motions

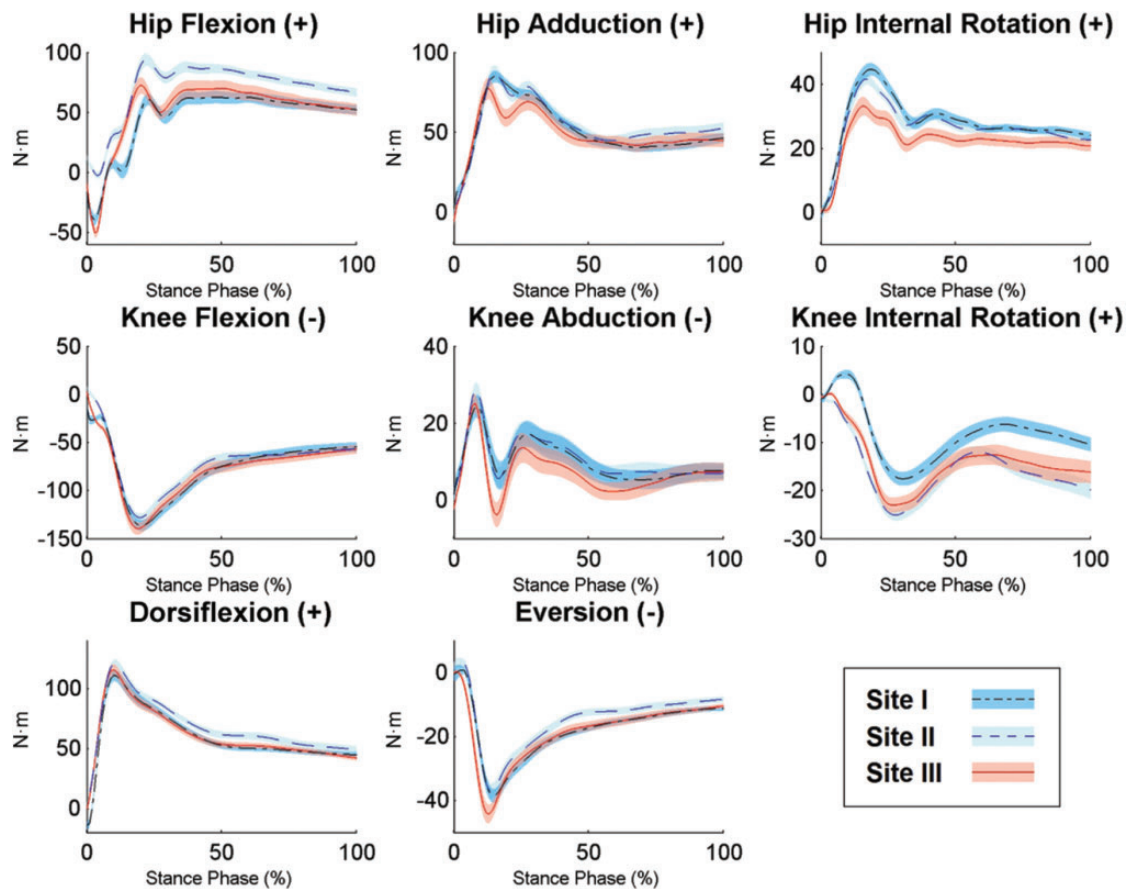


Figure 4. Mean kinetics for both sides of the single-leg cross drop landing from 0 to 500 ms after initial contact with the force plate, normalized to 101 data points, for all subjects at each of the 3 institutions. The shaded area represents standard error of the mean.

expressed the greatest ROMs, this does not fully account for the increased standard errors and decreased reliability at the more proximal joints. However, it has been shown previously that ROM factors heavily in CMC calculation, with larger ROM values having resulted in increased inter-session reliability of gait kinematic data.^{9,29} Kinematic ROM values generally decreased moving proximally up the leg, while kinetic ROM values were the greatest at the knee and lowest at the hip. The poor reliability of trunk flexion in the frontal plane could likely be attributed to the nondeterministic nature of lateral trunk movement during the SCD, whereas landing during the SCD invariably leads to hip, knee, ankle, and trunk flexion in the sagittal plane (eg, subjects may employ lateral trunk flexion, medial trunk flexion, or no flexion at all in the frontal plane). As such, using CMCs to determine the reliability of this rotation may be inappropriate; it may be more insightful to look at the reliability of peak values during this movement.

Moreover, it is possible that the SCD task is intrinsically more variable than a 2-leg landing, as landing on 1 leg places fewer constraints on the pelvis and generates greater ground reaction force,⁵ which can subsequently increase the variability in a movement.¹ The lateral perturbation of the trunk generated by the SCD is a possible confounder; variation in trunk position on landing has

been shown to influence ground reaction force, knee extensor moment, and plantar flexion,²⁸ and lateral trunk flexion has specifically been shown to affect pelvic stability during dynamic tasks.²⁶ This may not have been as evident in the frontal and transverse planes because flexion is the primary motion used to stabilize the body by attenuation of the impact of ground reaction force through increased flexion and quadriceps activation on landing.²⁷ Thus, differences in landing strategy with respect to trunk position and force attenuation may have led to increased variability in the sagittal plane during the SCD landing.

It has been shown previously that the within-session reliability of the SCD is moderate to good. In unpublished data collected at the primary testing site from which the within-session reliability of the SCD using a different cohort of athletes was determined, we observed intraclass correlations (ICC (3,1)) ranging from 0.443 to 0.850 for kinematic variables and 0.157 to 0.802 for kinetic variables tested in this study. For example, in the current study, sagittal plane knee angle and moment were highly reliable among the 3 testing sites; our previous data elicited ICCs of 0.831 and 0.690 for the left and right sagittal plane knee angles, respectively, and 0.796 and 0.802 for the left and right sagittal plane knee moments, respectively. Although the SCD task contains some intrinsic

variability within-center and within-subject, as the execution of the task and landing strategies employed may vary slightly between subjects and trials, the implementation of a standardized protocol as it pertains to task execution can minimize this source of variability. After the implementation of a standardized gait protocol, variation among kinematic measures decreased 20%.⁷ The present study implemented standardized instructions to subjects for completion of the SCD task. Standardized instructions are critical for a novel task like the SCD because performing and repeating the task correctly is necessary to preserve the goal of perturbation of the center of mass during the movement as it was originally designed. Additionally, the value in the SCD as a screening task for ACL injury is evident in the strategy and economy of task execution. In addition to challenging the subject to maintain adequate control of the trunk on landing, which has been linked to ACL injury risk,^{11,30,31} execution of the SCD requires multiplanar hip and knee control to successfully complete the movement. The SCD task is economical in that it requires less space and does not need to control for speed and foot-strike location as opposed to a run-and-cut or jump-and-cut task.^{6,17}

Extrinsic variability in multicenter studies of biomechanical movement can also be expected, especially because of the sensitivity of motion analysis to differences in the type of equipment used, system accuracy, neutral alignment, and marker placement.^{7,19} Variability in kinematic measures in the frontal and transverse planes has been shown to be partially explained by variation in marker placement¹⁹; the results of the present study indicate decreased reliability in frontal and transverse plane measures across institutions. Implementation of a standard method of instrumentation of subjects with markers—including accurate determination of anatomic landmarks that comprise the model—is imperative for minimizing the variability inherent in marker placement. Moreover, the use of model templates that are motion system-dependent and may identify markers in real-time can provide real-time feedback to the research team about whether a trial is “good,” allowing for additional trials to be collected to obtain the minimum number of necessary “good” trials. Failure to employ model templates and real-time tracking of markers at 1 site was partially why “good” motion data were present for only half of the original population, as markers became obstructed during critical points of task execution. In addition, kinematic and kinetic measures are subject to the participant’s standardized alignment during the static pose; variation in this initial alignment may subsequently alter the calculation of joint angle during movement. Subject instruction to repeat as closely as possible the static pose from which motion data are calculated is another approach for which a standardized protocol may help to reduce variability across institutions. Training of multicenter researchers and biomechanists prior to the implementation of these studies may be beneficial in improving extrinsic variability. Moreover, the differences in motion analysis systems and force plates between sites could have contributed to some variability among sites.

Prospective investigation of relatively rare events, such as ACL injury, may benefit from a multicenter approach as it increases the number of available subjects and may result in a more diverse subject pool. It is important to determine the reliability of tasks used to elicit risk factors for ACL injury across institutions and discuss the potential sources of variability, which will make the results of a multicenter collaboration more reliable. The SCD task shows moderate to strong reliability across 3 institutions during implementation of a set of standardized testing protocols, making it a reliable assessment of lower extremity injury risk across multiple institutions. The SCD is also a particularly useful screening task in that it challenges trunk control and includes multiplanar joint motion strategies in its execution. To ensure that a standardized protocol is used across all sites, it is essential to minimize the variability often inherent to multicenter studies.

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