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Abstract

Context: Abnormal movement patterns have been implicated in lower extremity injury. Reliable, valid, and easily implemented assessment methods are needed for the examination of existing musculoskeletal disorders and the investigation of predictive factors of lower extremity injury.

Objectives: To determine the reliability of experienced and novice testers in making visual assessments of lower extremity movement patterns and to determine construct validity of the visual assessments.

Design: Methodological study

Setting: University athletic department and research laboratory

Participants: Convenience sample of 30 undergraduate and graduate students who regularly participate in athletics (19.3±4.5 years). Testers: Two experienced physical therapists and one novice, post-doctoral fellow (non-clinician).

Main Outcomes: Videos of 30 athletes performing single leg squat (SLSquat) were used. Three testers observed the videos on two separate occasions and classified the lower extremity movement as Dynamic Valgus, No Change or Dynamic Varus. Classifications were based on the estimated change in frontal plane projection angle (FPPA) of the knee from single leg stance to maximum single leg squat depth. The actual FPPA change was measured quantitatively. Percentage agreement and weighted kappa were used to examine tester reliability and to determine construct validity of the visual assessment.

Results: Kappa values for intra- and intertester reliability ranged from 0.75-0.90, indicating substantial to excellent reliability. Percent agreement between the visual assessment and the quantitative FPPA change category was 90% with a kappa value of 0.85.

Conclusion: Visual assessments can be made reliably by experienced and novice testers. Additionally, movement pattern categories based on visual assessments were in excellent agreement with objective methods to measure FPPA change. Visual assessments may be used in the clinic to assess movement patterns associated with musculoskeletal disorders and in large epidemiologic studies to assess the association between lower extremity movement patterns and musculoskeletal injury.

Key Words: movement analysis, lower extremity, screening, knee valgus

INTRODUCTION

Abnormal movement patterns of the lower extremity have been implicated in noncontact anterior cruciate ligament (ACL) injuries[1] and other musculoskeletal pain problems such as patellofemoral pain[2-4] and acetabular labral tears.[5] In addition, correction of these abnormal movement patterns has been shown to prevent ACL injury[6] and is proposed to reduce symptoms in people with pre-existing pain conditions.[5, 7, 8] Thus, assessment of lower extremity movement patterns may provide an approach to guide treatment of existing musculoskeletal pain problems and to identify people at risk for future injury or musculoskeletal pain. To facilitate the examination of existing musculoskeletal disorders and the investigation of predictive factors of lower extremity injury, reliable, valid and feasible methods to assess lower extremity movement patterns are needed.

One method to assess lower extremity movement patterns is the Landing Error Scoring System (LESS).[9-11] The LESS uses a standard technique to make visual assessments of movement patterns during a drop vertical jump. The LESS has been shown to be reliable and valid,[9-11] however the drop vertical jump is a relatively high level activity that may not be the best approach to assess movement patterns in patients with existing injury or in athletes who participate in sports that do not involve landing from a jump. In addition, the drop vertical jump is a bilateral activity that may allow the participant to use one limb to compensate for the other. Visual assessment of the single leg squat, a unilateral limb task, may provide an alternative to the LESS.

We have developed standardized methods using a visual assessment of the frontal plane projection angle (FPPA) to classify the lower extremity movement pattern during a single leg squat (SLSquat). The FPPA is a 2 dimensional (2D) representation of the lower extremity position[12] that has been used to identify differences between women with patellofemoral pain and controls,[4, 13] between men and women[12] and for detecting change in movement patterns after specific training.[14] We established specific criteria to define the categories of lower extremity movement pattern based on the change in FPPA (FPPA change) during motion. The tester observes the angle formed between a line that bisects the thigh and a line that bisects the lower leg. During movement tests, the tester compares the FPPA at the start position and to the FPPA at the end position. For example, to assess a single leg squat, the examiner compares the FPPA during the start position of single leg stance to the end position of maximum squat depth. The difference observed in FPPA from the start to the end position can then be classified into one of three categories, No Change, Dynamic Valgus defined as change in the valgus direction or Dynamic Varus defined as change in the varus direction. We have used this assessment extensively in the clinical setting, however we have not assessed the rater reliability or the construct validity of our visual assessments.

The purpose of this study was to assess the intratester and intertester reliability of three testers, two experienced and one novice, categorizing the lower extremity movement pattern demonstrated during a SLSquat. A standardized protocol was used to assess videos of healthy participants performing the SLSquat movement. We hypothesized the testers, both experienced and novice, would demonstrate good to excellent reliability using the standardized methods. In addition, we used the objective measure of quantifying FPPA as described by Willson[12] to determine the construct validity of our visual assessments. We hypothesized that we would demonstrate good to excellent agreement between our visual assessments and the quantitative FPPA change.

METHODS

Participants

This study was approved by the Human Research Protection Office of *Blinded*. Participants in this study were a subset from a prospective cohort study developed to assess risk factors for athletic injury. The cohort was a convenience sample including both undergraduate and graduate students who regularly participated in athletics. All participants were 18 years of age or older and were recruited to participate in the longitudinal study that included a focused examination of hip range of motion, hip muscle strength, provocative tests to assess for hip joint pathology and movement pattern assessment. As part of the study, participants were videotaped performing a SLSquat. Data collection occurred over a period of two years. Participants with an existing injury that limited their ability to perform the examination items were excluded. All participants read and signed an informed consent statement approved by Human Research Protection Office of *Blinded* before participating in the study.

Movement Task Description and Video Taping Procedures

A standardized method was used to collect videos of the SLSquat. A digital camera (Sony Cyber-shot DSC-w100; Sony, Tokyo, Japan) was placed on a tripod at the level of the participant's knee and approximately two meters anterior to the participant.[12] The image taken included the participant's feet to the mid-thoracic region throughout the entire movement. To eliminate the effect of shoe wear on limb movement, the participant removed their shoes prior to testing.

A research assistant instructed the participant in the movement and performed the video capture. The research assistant described and demonstrated the SLSquat to the participant. The research assistant stood next to rather than in front of the participant while demonstrating the movement so the participant could observe the appropriate depth of the squat, however could not observe the pattern of lower extremity motion in the frontal plane. The participant was instructed to start with their arms across their chest and their weight distributed evenly on both feet. When cued to move, the participant raised their untested limb by flexing the knee while maintaining the hip in 0° of extension. The participant then performed the SLSquat and returned to the standing positioning with weight distributed evenly on both feet. The participant was encouraged to squat as far as they could comfortably. If the participant did not reach a minimum of 60° of knee flexion, as judged visually by the research assistant, they were instructed to increase the depth of the squat.

After instruction, the participant was allowed to practice the movement until they felt comfortable with their performance. If the participant required more than three repetitions for practice, they were allowed 2-3 minutes to rest prior to video capture. Once the participant was comfortable with the movement, one movement was recorded. The video was collected from standing with both feet on the ground, through the SLSquat movement and back to initial standing position. The recording was repeated if the participant lost their balance during the movement or if the research assistant determined that the squat was not of sufficient depth. Loss of balance was defined as the participant 1) placed their untested limb on the ground before completion of the movement, 2) demonstrated extraneous movement of the upper extremities, 3) trunk lean that resulted in excessive motion of the untested limb 4) moved the stance limb by either sliding, hopping or twisting the stance foot. The participant then repeated the process on the opposite limb, yielding one recording of one trial for each limb for each subject.

Video Selection for Reliability

Over six testing sessions, 140 movements (70 participants) were collected for the ongoing longitudinal study. From the 140 videos, a second research assistant (XX) not involved in the original video recordings or the visual assessment selected the videos to be used for reliability testing. The research assistant, who had minimal knowledge of the movement patterns of interest, was instructed to select videos that included variable movements. The research assistant was also instructed to exclude videos based on the following criterion: the squat did not appear to achieve knee flexion of 60° or the participant lost his/her balance during the testing. A total of 30 videos of 30 participants one limb only, were selected for reliability testing. Of the 30 subjects, 18 were male and 12 were female with average age of 19.3±4.5 and BMI of 23.8±3.6. To reduce the likelihood of tester recall, the research assistant assigned a dummy code to each video and randomly ordered the videos for each testing session. Compact discs were developed and distributed to each tester along with written instructions for performance of the visual assessment and a data collection sheet for each testing session.

Testers

Three testers participated in the study. The first tester (experienced) (XXX) is a board-certified clinical specialist in orthopaedic physical therapy and has 13 years of clinical and research experience. The second tester (experienced) (XXX) is a physical therapist with 24 years of clinical and research experience specific to the lower extremity. The third tester (novice) (XXX) is a post-doctoral fellow who has four years of research experience, only one of these years specific to musculoskeletal assessment and no clinical background. The first and second testers were involved in method development and standardization of the movement assessment. The third tester was trained by the second tester. Training included review of a written manual describing the criteria for group classification, followed by observing and discussing 8-10 practice videos together.

Visual Assessment Procedures

On two separate occasions, each tester viewed the selected videos and classified the movement pattern demonstrated by each participant. To reduce the likelihood of tester recall, a minimum of one week occurred between the two testing sessions. No discussion of the testing procedures or the classification criteria occurred during the testing.

Each tester classified the movement pattern using methods developed. For each video, they compared the FPPA in single leg stance (start position) to the FPPA at the maximum depth of the squat movement (end position). Based on her visual appraisal, the tester determined if the FPPA changed more than 10° from the start position to the end position. We used the 10° criteria, because during the development of our methods, we found a 10° change to be easily detectable by visual appraisal. If the angle did not change more than 10°, the movement was classified as “No Change”. If the angle changed more than 10°, the tester also determined if the knee moved toward or away from the midline of the body. Movement toward the midline was classified as “Dynamic Valgus” and movement away from the midline was classified as “Dynamic Varus” (Figure 1).

Each tester was allowed to view each video as often as she needed, however was not allowed to stop or slow down the rate of the video. In addition, she was not allowed to measure the angle using imaging software or goniometric devices.

Objective Measurement Procedures

The videos were also used to obtain objective 2D measures of the FPPA change. The research assistant who selected the videos performed all measurement methods. Using a free and open source program, VLC media player (VideoLAN non-profit organization, Paris, France) snapshots were obtained by capturing still frames of the video at the start position and end position. The start position was defined as the frame when the participant had placed all of their body weight on the tested limb and just before the tested knee started to flex. The end position was defined as the frame when knee had flexed maximally and just before the tested knee started to extend.

Google SketchUp version 7.1 (Google Inc, Mountain View, CA) was used to perform the angle measurements on the captured snapshots. For each start and end position, two lines were drawn to represent the FPPA, one that bisected the thigh and one that bisected the lower leg (Figure 1). The 360° protractor function in Google SketchUp was used to measure the angle formed by the two lines. Precision was set to 1/10 degree. The FPPA change was determined by subtracting the start FPPA from the end FPPA. Positive values represented movement of the knee toward the midline and negative values represented movement of the knee away from the midline. To assess the intratester reliability of the FPPA change, fifteen videos were measured a second time, two weeks following the first measurement session. The measurement reliability was high, $ICC_{2,1}$ was .98 (95% CI: .95-.99) with standard error of measurement (SEM) (95%) of 1.79° (95% CI: 3.58°).

Quantitative FPPA change based on the objective measures were categorized as follows: values less than or equal to 10° in the either negative or positive direction were categorized as No Change; > 10° in the positive direction were categorized as Dynamic Valgus; > 10° in the negative direction were categorized as Dynamic Varus.

The group classification from the first session of the two experienced testers was used to compare the quantitative FPPA change. In cases where the two testers agreed, the agreed upon classification was used. In the two cases where the testers disagreed, a third expert was consulted to determine the final classification. This consensus rating is considered our best estimate of the “true” condition.

Statistical Analysis

Statistical analysis was completed using SAS version 9.1 of the SAS System for Linux (SAS Institute Inc. Cary, NC). Descriptive statistics were calculated for demographics. Percentage of observations yielding perfect agreement (i.e., percent agreement) and weighted kappa coefficients[15] with 95% confidence intervals (CIs) were used to examine the intratester and intertester reliability of the visual assessment classification and to compare the visual assessment category to the quantitative FPPA change category based on the objective measures. We used weighted kappa coefficients to represent the fraction of agreement beyond that expected by chance, and account for the magnitude of the disagreement between readings. Intratester agreement statistics were reported comparing session one and session two readings of each tester. Intertester agreement statistics were reported comparing session one classifications across testers. P value < .05 was considered significant.

RESULTS

The percentage agreement and tester reliability of the visual assessment classification are provided in Table 1. Weighted kappa values ranged from 0.80-0.90 for intratester reliability and from 0.75-0.90 for intertester reliability, indicating substantial to excellent reliability.[16] Table 2 represents the number of participants classified as Dynamic Valgus, No Change, and Dynamic Varus for each tester's session one and session two readings. Table 3 represents the number of participants classified by each pair of testers.

The percentage agreement between the visual assessment category and the quantitative FPPA change category was 90% (95% CI: 78-100%) with a weighted kappa of 0.85 (95% CI: 0.69-1.0) (Table 4).

DISCUSSION

The goal of this study was to assess the reliability of experienced and novice testers in making visual assessments of lower extremity movement patterns during a SLSquat and to determine the construct validity of our visual assessments compared to a quantitative measure of FPPA change. We hypothesized that the testers, both experienced and novice, would demonstrate good to excellent reliability using the standardized methods and that movement pattern categories based on visual assessments would be in good to excellent agreement with categories based on the quantitative FPPA change. Both hypotheses were supported.

We have demonstrated that visual assessments can be made reliably by testers of variable experience levels when standardized methods are used. In addition, there was substantial agreement between the visual assessment and the quantitative FPPA change category. The standardized criteria used during the visual assessments to determine classifications of lower extremity movement patterns requires minimal training. Thus, it would be feasible to use visual assessment in the clinic to identify and treat movement-related musculoskeletal disorders and in large research studies to assess the association between lower extremity movement patterns and musculoskeletal injury.

Our study builds upon previous studies that report tester reliability of movement assessment specific to the lower extremity.[17-20] One of the earliest studies to assess SLSquat was performed by Chmielewski et al.[18] The authors reported low reliability (weighted kappa: 0-0.55) among three experienced testers when assessing SLSquat. From their experience, they hypothesized that reliability would likely improve with standardized methods that provided specific criteria to assist with decision making. We believe the standardization and inclusion of strict criteria to define each classification has resulted in our high levels of agreement. The testers in our study were provided standard instruction to determine FPPA (bisection of thigh and lower leg), specific timing of FPPA visualization (single leg stance and maximum depth of squat) and quantitative value of FPPA change (10°) to make their visual assessment.

Ekegren et al[21] reported substantial reliability among experienced testers assessing a different task, the drop vertical jump. They also used different criteria to classify lower extremity movement pattern. While our decisions focused on the motion of the thigh relative to the lower leg, Ekegren et al[21] used the relationship of the patella to the big toe. They classified the lower extremity movement pattern as follows: "if the patella moves inward and ends up medial to the first toe, rate the individual as high risk [for ACL injury] or if the patella lands in line with the first toe, rate the individual as low risk [for ACL injury]". Similar to our study, they reported high reliability (kappa coefficients 0.75-0.85), however we believe our methods more directly represent the relationship of the lower leg to the thigh during the SLSquat. During initial method development, we attempted to use the criteria reported by Ekegren et al.[21] We found, during performance of SLSquat, the patella would often end in line with the first toe, however the end position of the knee appeared to be in dynamic valgus position. This may suggest that use of the patella is appropriate for the drop vertical jump test, however our methods may be more suited for visual assessment of the SLSquat.

Other studies have reported on the tester reliability of a score representing the movement pattern of the trunk, pelvis and lower extremity combined.[9, 11, 20] In each of these studies, explicit criteria were provided to assess the combined movement. Crossley et al[20] reported substantial to excellent reliability (kappa: 0.60-0.80) among experienced testers assessing a SLSquat. Padua et al[9] used the LESS to assess the drop vertical jump and reported the intertester reliability to be good ($ICC_{2,k}$: 0.84). Although movements of the lower extremity were observed for the combined score, the authors of these studies did not assess the reliability of testers specifically judging the movement pattern of the lower extremity. Assessing the combined movement quality may be useful, however the assessment of the lower extremity may provide more specific information for lower extremity disorders.

We have demonstrated that a tester with minimal experience assessing lower extremity movement patterns may classify movements reliably if provided with training and specific criteria to determine the classifications. To our knowledge, this is the first study to report the reliability of a novice tester categorizing lower extremity movement patterns during a single leg squat. Onate et al[11] reported excellent expert versus novice intertester reliability using the LESS to assess a drop vertical jump, thus supporting our findings that a novice tester may reliably assess lower extremity movement patterns. Our methods may be used by coaches during preseason screening to assess movement patterns of athletes or by healthcare providers to identify those who may benefit from specific treatment to address impaired movement patterns. In addition, use of our methods may improve our ability to prospectively assess the relationship between movement patterns and musculoskeletal injury by increasing the number of testers that may be used during screening studies.

The testers did not demonstrate perfect agreement in the lower extremity movement pattern classifications. In review of the data, the novice tester was more likely to classify a movement pattern as Dynamic Valgus, than the experienced testers. This may have important implications. If the test is used as a screening assessment to identify those athletes at risk for injury, the assessments made by the novice tester would result in a greater number of athletes identified as “at risk”. This would result in athletes receiving additional training or treatment that may not be necessary. If the risk or cost of treatment is high relative to the possible benefits, an experienced clinician may be preferred. However, the novice tester’s intratester reliability was high suggesting that novice testers may serve as the initial screener to identify individuals to be referred to an experienced clinician for a more thorough movement pattern assessment.

We have also demonstrated that movement pattern categories based on visual assessments are in excellent agreement with categories based on the quantitative FPPA change category. This is the first study to report on three movement pattern categories. Previous studies have focused primarily on the dynamic knee valgus[4, 19-21] as a potential risk factor for injury and labeled all other lower extremity movements as “good” or “low risk for injury”. We have reported a third classification, a varus-like movement pattern that may be described as a dynamic knee varus. There are no studies to implicate a dynamic knee varus as a risk factor for injury, however varus alignment of the knee has been implicated in the progression of osteoarthritis.[22] The association between a varus alignment and progression of osteoarthritis suggests that it may be important to identify a dynamic knee varus in future studies. Dynamic knee varus may be a risk factor that has yet to be identified, and therefore should be further explored. In addition, excluding dynamic knee varus from the “good” or “low risk for injury” categories may provide a more homogenous group of participants who are classified as having no deviation.

Our study findings should be considered in light of several limitations. The first limitation pertains to the criteria used to determine the Dynamic Valgus or Dynamic Varus classification. We do not know if an FPPA change greater than 10° is associated directly to injury or musculoskeletal pain. Based on our clinical experience with people reporting hip or knee pain, we have found that people who demonstrate Dynamic Valgus during a single leg squat often report an increase in their pain. If the Dynamic Valgus is corrected, this pain often reduces or abolishes. We therefore felt it important to standardize this test and assess its reliability and validity. As stated previously, during the development and refinement of our methods, we found a FPPA change to be representative of the lower extremity movement pattern that we were observing clinically and that 10° was easily detected by our visual assessment. Future studies with larger sample sizes, however are needed to assess the sensitivity, specificity and predictive values associated with our methods.

We have not validated our visual assessments using laboratory-based three dimensional (3D) motion analysis, the gold standard for movement pattern assessment. We instead compared our visual assessment to 2D projection angles using video recordings. Projection angles, while not a direct substitute for 3D angles,[14] have been shown to be correlated to 3D angles.[23] We believe our methods were a reasonable first step to validation that can be easily replicated in clinical settings where 3D motion analysis is not available. Comparison of our visual assessments to 3D motion is needed and is the focus of our next study.

We did not standardize the SLSquat for depth or speed, however this is typical of clinical practice. Variations in either squat depth or speed may affect the angle changes measured and observed. The testers, however were able to determine the classifications of the lower extremity movement patterns with substantial to excellent reliability despite this variability. This limitation is being addressed in our current study where the depth of the squat is standardized and the time to complete the movement is being collected as a covariate.

To assess tester reliability, we used a video recording of one SLSquat that could be viewed by each tester multiple times. Using a video recorder would not be feasible in clinical practice, however our methods for visual assessment may be used by the clinician to observe one or multiple movements performed by their patient. We chose to use the video recordings to reduce the variability in the participant’s performance. The participant’s performance of the SLSquat may vary across testing sessions, resulting in different movement patterns being assessed during the two sessions, thus limiting our ability to accurately assess tester reliability. We therefore used one video recording so the participant’s performance would remain stable across testing sessions.

We did not assess test-retest reliability by observing participants on multiple occasions. Test-retest reliability would be important, particularly if lower extremity movement assessment were to be implemented as an outcome measure for treatment. Stensrud et al[19] reported fair to moderate test-retest reliability when one tester assessed SLSquat, however the criteria to classify the movement pattern was not as specific as those outlined in the current study. We believe use of our standardized methods will improve upon the test-retest results previously reported. Future work will include movement testing performed by the participants on multiple occasions.

CONCLUSION

With training and use of standardized techniques, testers both experienced and novice can reliably classify lower extremity movement patterns based on visual assessment. Although experience testers demonstrate higher intertester reliability, reliability between the novice and experienced testers was substantial, indicating novice testers may be used initial screening programs. Additionally, movement pattern categories based visual assessments were found to be in excellent agreement with objective methods to measure FPPA change. Visual assessment may be used in the clinic to categorize movement patterns that may be associated with musculoskeletal disorders, and in large epidemiologic studies to assess the association between lower extremity movement patterns and musculoskeletal injury. Future studies are needed to determine if an association exists between the identified movement patterns and musculoskeletal disorders.

KEY POINTS

- With training and use of standardized techniques, testers both experienced and novice reliably classified lower extremity movement patterns based on visual assessment.

- Movement pattern categories based visual assessments were in excellent agreement with objective methods to measure FPPA change.
- Visual assessment based on the methods described in this study may be used in the clinical setting, as well as large epidemiologic studies and large screening assessments for sport participation to identify distinct categories of lower extremity movement pattern.

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TABLE 1. Intratester and intertester reliability for visual assessment of the single leg squat.

Examiners	Percent Agreement (95% CI)	Weighted Kappa (95% CI)
Intratester reliability		
1	87 (73, 100)	0.80 (0.61, 0.99)
2	93 (83, 100)	0.90 (0.77, 1.00)
3	90 (78, 100)	0.84 (0.67, 1.00)
Intertester reliability		
1 *vs.* 2	93 (83, 100)	0.90 (0.77, 1.00)
1 *vs.* 3	83 (68, 98)	0.75 (0.54, 0.96)
2 *vs.* 3	83 (68, 98)	0.75 (0.54, 0.96)

1 = experienced tester
2 = experienced tester
3 = novice tester

TABLE 2. Kappa tables for intratester ratings. **Each tester viewed the videos and classified the movement pattern on two separate occasions. Each box represents the classifications provided by one tester.**

Tester 1 Experienced tester		**Session 2**			
		Dynamic Valgus	No Change	Dynamic Varus	Total
Session 1	Dynamic Valgus	13	3	0	16
	No Change	1	10	0	11
	Varus	0	0	3	3
	Total	14	13	3	30

Tester 2 Experienced tester		**Session 2**			
		Dynamic Valgus	No Change	Dynamic Varus	Total
Session 1	Dynamic Valgus	15	1	0	16
	No Change	1	10	0	11
	Dynamic Varus	0	0	3	3
	Total	16	11	3	30

Tester 3 Novice tester		**Session 2**			
		Dynamic Valgus	No Change	Dynamic Varus	Total
Session 1	Dynamic Valgus	18	3	0	21
	No Change	0	6	0	6
	Dynamic Varus	0	0	3	3
	Total	18	9	3	30

Cell values are the number of participants for each pair of classifications.

TABLE 3. Kappa tables for intratester ratings. **Classifications from the first session of each tester were used for intertester reliability testing.**

		Tester 2 Experienced tester			
		Dynamic Valgus	No Change	Dynamic Varus	Total
Tester1 Experienced Tester	Dynamic Valgus	15	1	0	16
	No Change	1	10	0	11
	Dynamic Varus	0	0	3	3
	Total	16	11	3	30

		Tester 3 Novice tester			
		Dynamic Valgus	No Change	Dynamic Varus	Total
Tester1 Experienced Tester	Dynamic Valgus	16	0	0	16
	No Change	5	6	0	11
	Dynamic Varus	0	0	3	3
	Total	21	6	3	30

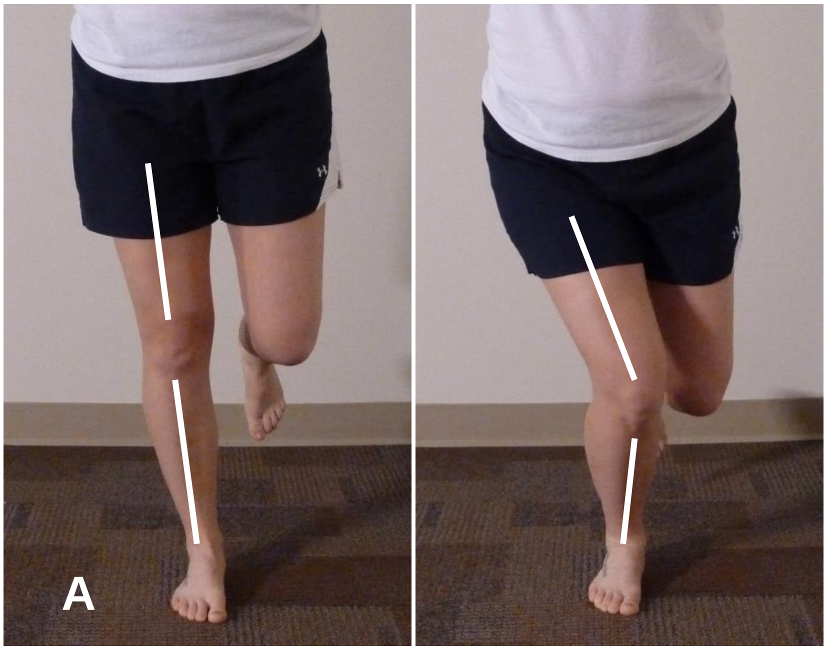
		Tester 3 Novice tester			
		Dynamic Valgus	No Change	Dynamic Varus	Total
Tester2 Experienced Tester	Dynamic Valgus	16	0	0	16
	No Change	5	6	0	11
	Dynamic Varus	0	0	3	3
	Total	21	6	3	30

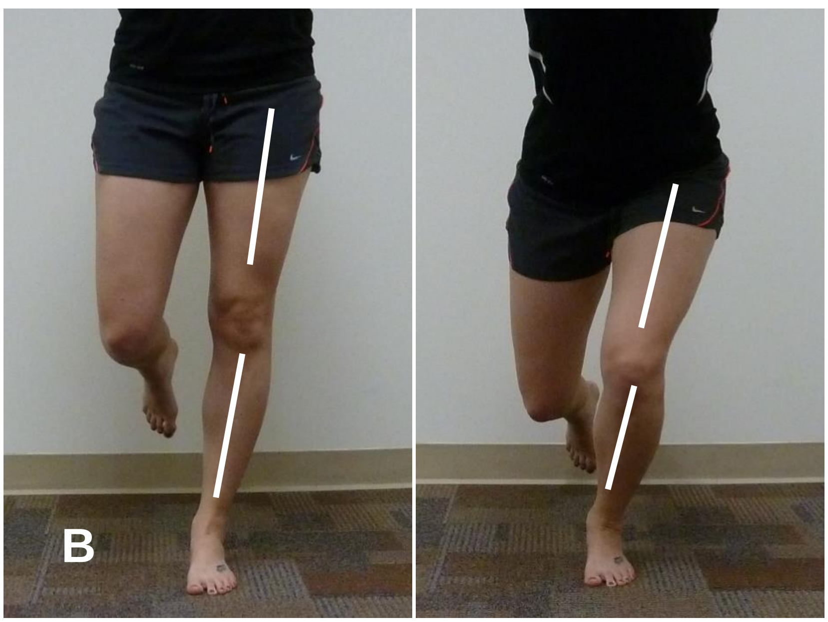
Cell values are the number of participants for each pair of classifications.

TABLE 4. Kappa table for comparison of categories based on visual assessment and quantitative FPPA change.

		Visual Assessment (consensus rating)			
		Dynamic Valgus	No Change	Dynamic Varus	Total
Quantitative FPPA change	Dynamic Valgus	14	1†	0	15
	No Change	2*	10	0	12
	Dynamic Varus	0	0	3	3
	Total	16	11	3	30

* The FPPA change values for these two discrepancies are 3.2° and 8.0°.
† The FPPA change value for this discrepancy is 13.4°


A


B

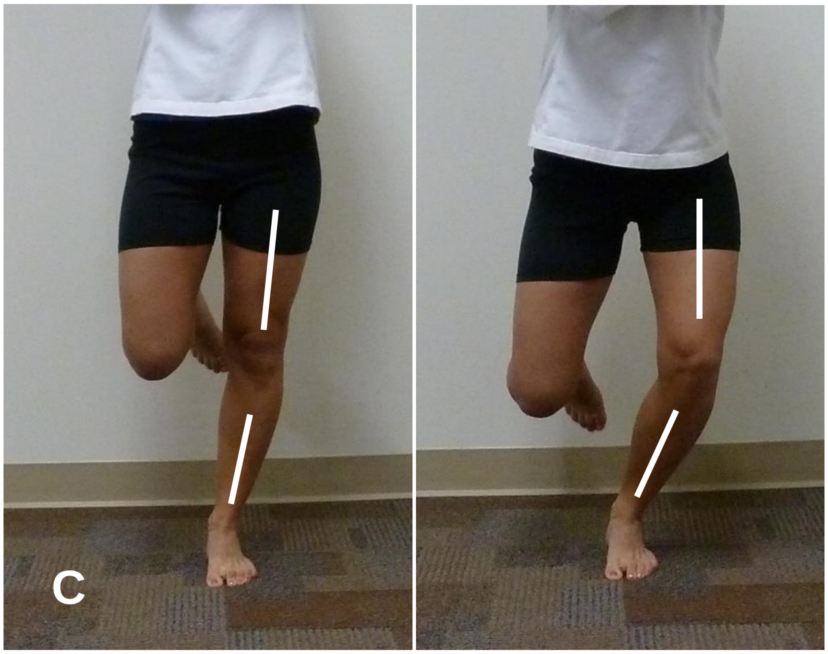


FIGURE 1. Images to demonstrate methods for objective measurement of the frontal plane projection angle (FPPA) change. Two lines are drawn to represent the FPPA, one bisects the thigh segment and one bisects the lower leg. The angles were then measured using a protractor function in measurement software. FPPA change was calculated by subtracting the end FPPA (figures in right column) from the start FPPA (figures from the left column). Representative examples of the three lower extremity movement classifications are provided. A) Dynamic Valgus = angle between the femoral bisection and lower leg bisection changes more that 10° and the knee moves toward the midline of the body. B) No Change = angle between the femoral bisection and lower leg bisection changes less than 10° during the motion. C) Dynamic Varus – angle between the femoral bisection and lower leg bisection changes more than 10° and the knee moves away from the midline of the body.