Journal of Sport Rehabilitation, 2012, 21, 7-11

Reliability of 2-Dimensional Video Assessment of Frontal-Plane Dynamic Knee Valgus During Common Athletic Screening Tasks

Allan Munro, Lee Herrington, and Michael Carolan

Context: Two-dimensional (2D) video analysis of frontal-plane dynamic knee valgus during common athletic screening tasks has been purported to identify individuals who may be at high risk of suffering knee injuries such as anterior cruciate ligament tear or patellofemoral pain syndrome. Although the validity of 2D video analysis has been studied, the associated reliability and measurement error have not. ***Objective:*** To assess the reliability and associated measurement error of a 2D video analysis of lower limb dynamic valgus. ***Design:*** Reliability study. ***Participants:*** 20 recreationally active university students (10 women age 21.5 ± 2.3 y, height 170.1 ± 6.1 cm, weight 66.2 ± 10.2 kg, and 10 men age 22.6 ± 3.1 y, height 177.9 ± 6.0 cm, weight 75.8 ± 7.9 kg). ***Main Outcome Measurement:*** Within-day and between-days reliability and measurement-error values of 2D frontal-plane projection angle (FPPA) during common screening tasks. ***Interventions:*** Participants performed single-leg squat and drop jump and single-leg landings from a standard 28-cm step with standard 2D digital video camera assessment. ***Results:*** Women demonstrated significantly higher FPPA in all tests except the left single-leg squat. Within-day ICCs showed good reliability and ranged from .59 to .88, and between-days ICCs were good to excellent, ranging from .72 to .91. Standard error of measurement and smallest detectable difference values ranged from 2.72° to 3.01° and 7.54° to 8.93°, respectively. ***Conclusions:*** 2D FPPA has previously been shown to be valid and has now also been shown to be a reliable measure of lower extremity dynamic knee valgus. Using the measurement error values presented along with previously published normative data, clinicians can now make informed judgments about individual performance and changes in performance resulting from interventions.

Keywords: measurement error, frontal-plane projection angle, outcome measures

Injury to the knee-joint complex is one of the most commonly occurring injuries in a number of sports.[1,2] Most knee injuries such as anterior cruciate ligament tears and patellofemoral pain syndrome occur through noncontact or overuse mechanisms.[1,3] The cause of such noncontact and overuse injuries is multifactorial. Abnormal lower limb biomechanics during activity has been widely postulated as a factor in the etiology of both traumatic and overuse knee injury.[3–6] Altered hip, knee, and ankle kinematics have been termed dynamic knee valgus[4] and are widely reported to be related to knee injury.[3,4,6] Other factors include changes in lower limb kinetics and muscle strength or length.

A number of screening tests have been used in the literature to assess dynamic knee valgus. These have included the single-leg squat[5,7,8] (SLS), drop vertical jump,[4,9,10] drop landing,[11] and single-leg landing[12] (SLL). Most of these studies used 3-dimensional (3D) motion analysis to quantify lower limb biomechanics, and these methods are seen as the gold standard for analyses of this type. However, because of the financial, spatial, and temporal cost of 3D motion analysis it is not practical for most clinical settings or for use in large screening programs useful to sport. Therefore, 2-dimensional (2D) techniques, which employ less expensive, portable, and easy-to-use equipment, may be more useful. Two-dimensional analysis has been used previously to measure knee-valgus angle in athletic, general, and injured populations.[7,9]

Willson et al[7] introduced the use of frontal-plane projection angle (FPPA) of the knee to quantify knee-valgus motion during the SLS test. Two recent studies have looked at the validity of 2D video analysis in quantifying FPPA of the knee compared with existing 3D techniques.[5,13] Two-dimensional peak FPPA was shown to account for 58% to 64% of the variance in average peak 3D knee-abduction angle between subjects during side-step and side-jump activities.[13] Willson and Davis[5] found that 2D FPPA reflected 23% to 30% of the variance of 3D values. More interesting, they found that 2D FPPA was significantly correlated with both knee

Munro is with the Directorate of Sport, Exercise and Physiotherapy, and Herrington and Carolan, the Dept. of School of Health, University of Salford, Salford, UK.

external rotation and hip adduction, 2 major components of dynamic valgus. They concluded that although 2D analysis is not a substitute for 3D measurements of lower limb kinematics, it is useful for screening knee-joint FPPA to identify high-risk athletes.[5,13] Individuals who demonstrate excessive 2D knee valgus are thought to demonstrate 3D kinematics that leaves them at high risk of knee injuries such as anterior cruciate ligament tears and patellofemoral pain syndrome. Furthermore, 2D analysis may be useful for evaluating the value of training and intervention programs in reducing frontal-plane dynamic knee valgus.[9]

To date, only intraclass correlation coefficients for within-day reliability of FPPA have been presented,[7] with no study presenting measurement error values associated with these tests. Therefore, further investigation of the reliability of 2D FPPA is needed before it can be recommended for use in screening tests. If the reliability and measurement error of this screening method can be established, clinicians will be able to use the tests with confidence while also being able to evaluate individual performance more informatively. Therefore, the aim of this study was to assess the reliability and associated error measurement of 2D video analysis of lower limb dynamic valgus.

Methods

Participants

Twenty recreationally active participants (10 women age 21.5 ± 2.3 y, height 170.1 ± 6.1 cm, weight 66.2 ± 10.2 kg and 10 men age 22.6 ± 3.1 y, height 177.9 ± 6.0 cm, weight 75.8 ± 7.9 kg), all of whom were university students, volunteered for the study. Subjects were required to be free from lower extremity injury, defined as any complaint that stopped them from undertaking their normal exercise routine, for at least 6 months before testing and have no history of lower extremity surgery. To qualify as recreationally active, subjects were required to participate in a minimum of 30 minutes of physical activity three times a week on a regular basis over the past 6 months, which included recreational and competitive sports. All participants gave written informed consent to participate, and the university research and ethics committee approved the research.

Procedures

Before testing, markers were placed on the lower extremity of each subject to approximate the radiographic landmarks employed by Willson et al[7] and Willson and Davis.[5] Markers were placed at the midpoint of the femoral condyles to approximate the center of the knee joint, midpoint of the ankle malleoli for the center of the ankle joint, and on the proximal thigh along a line from the anterior superior iliac spine to the knee marker. The midpoints were determined using a standard tape measure, and all markers were placed by the same experimenter. These markers were used in order for FPPA of the knee to be determined from digital images using Quintic software package (9.03 version 17).

Testing took place on 2 force plates; this gave the participants a reference point and ensured that the trials were undertaken in front of the digital video camera (Sony Handycam DCR-HC37), which was wall mounted at a height of 60 cm, 10 m away from the force plates. Digital video footage was recorded at a standard 10× optical zoom throughout each trial to standardize the camera position between subjects, after which the footage was downloaded to Quintic. A single experimenter digitized the markers placed on the subject, enabling FPPA of the knee to be ascertained.

Participants were tested twice on day 1 (tests 1 and 2), with the tests separated by 1 hour, to assess within-day reliability. Participants were then tested again exactly 1 week later (test 3) at the same time of day to assess between-days reliability.

Subjects were allowed practice trials before each test until they felt comfortable; this was typically 2 or 3 trials. After familiarization each participant performed 3 trials of each test. Both legs were tested and analyzed for all tests.

SLS. Subjects were asked to stand on the test limb, facing the video camera. They were asked to squat down as far as possible, to at least 45° knee flexion, over a period of 5 seconds. Knee-flexion angle was checked during practice trials using a standard goniometer (Gaiam-Pro), then observed by the same examiner throughout the trials. There was also a counter for each participant over this 5-second period, in which the first count initiates the movement, the third indicates the lowest point of the squat and the fifth indicates the end. This standardizes the test for the participant, thereby reducing the effect of velocity on knee angles. Trials were only accepted if the subject squatted to the minimum desired degree of knee flexion and maintained balance throughout.

Drop Jump. Subjects stood with feet shoulder-width apart on a 28-cm-high step, 30 cm from the force plates. They were instructed to lean forward and drop from the step as vertically as possible, in an attempt to standardize landing height.[14] Subjects were required to land with one foot on each of the force plates, then immediately perform a maximal vertical jump, finally landing back on the force plates. There were no set instructions regarding arm movement, only for the subjects to perform the jump naturally. The initial landing from the step was used for analysis purposes.[10]

Single-Leg Landing. As with the drop-jump task, subjects dropped from a 28-cm step, again leaning forward and dropping as vertically as possible. They were asked to take a unilateral stance on the contralateral limb and to step forward to drop onto the force platform corresponding to the landing leg, ensuring that the contralateral leg made no contact with any other surface.[10]

FPPA. FPPA of the knee was measured as the angle subtended between the line from the markers on the proximal thigh to the knee joint and the line from the knee joint to the ankle[7] at the frame that corresponded with the point of maximum knee flexion, as shown in Figure 1. Positive FPPA values reflected knee valgus, excursion of the knee toward the midline of the body so that the knee marker was medial to the line between the ankle and thigh markers, and negative FPPA values reflected knee varus.

Statistical Analyses

All statistical analysis was conducted using SPSS for Windows version 16.0 (SPSS Inc, Chicago, IL). Independent *t* tests were carried out to assess differences between men and women and left and right legs. Alpha levels were set at .05 for all tests. Intraclass correlation coefficients ($ICC_{3,1}$)[15] assessed within- and between-sessions reliability, from which 95% confidence intervals (CI), standard error of measurement (SEM), and smallest detectable difference (SDD) were calculated to establish random error scores. ICC values were interpreted according to the following criteria[16]: poor <.40, fair .40 to .70, good .70 to .90, and excellent >.90.

SEM was calculated using the formula[17]

$$\text{SD (pooled)} \times \sqrt{1 - \text{ICC}}$$

and SDD was calculated from the formula[18]

$$1.96 \times \sqrt{2} \times \text{SEM}$$

Results

First, all data from tests 1–3 were analyzed for differences between sex and limbs. Women demonstrated significantly higher valgus ($P < .05$) than men for all tests except SLS left ($P = .057$), so men and women were analyzed separately for all further analysis. No differences were found between left and right legs ($P > .05$) in either sex, so men and women were grouped during all further analysis.

Within-session reliability was shown to be good for all tests, with the exception of SLS in women. ICCs and 95% CIs are shown in Table 1. ICCs ranged from .59 to .88 for women, the SLS accounting for the fair score of .59, and men's ICCs ranged from .79 to .86.

Table 1 Within-Day Intraclass Correlation Coefficients (ICC) and 95% Confidence Intervals (CI) for the 3 Tests

Test	ICC	95% CI
Men		
single-leg squat	.86	.77–.92
drop jump	.83	.72–.90
single-leg landing	.79	.65–.87
Women		
single-leg squat	.59	.31–.75
drop jump	.88	.80–.93
single-leg landing	.75	.58–.85

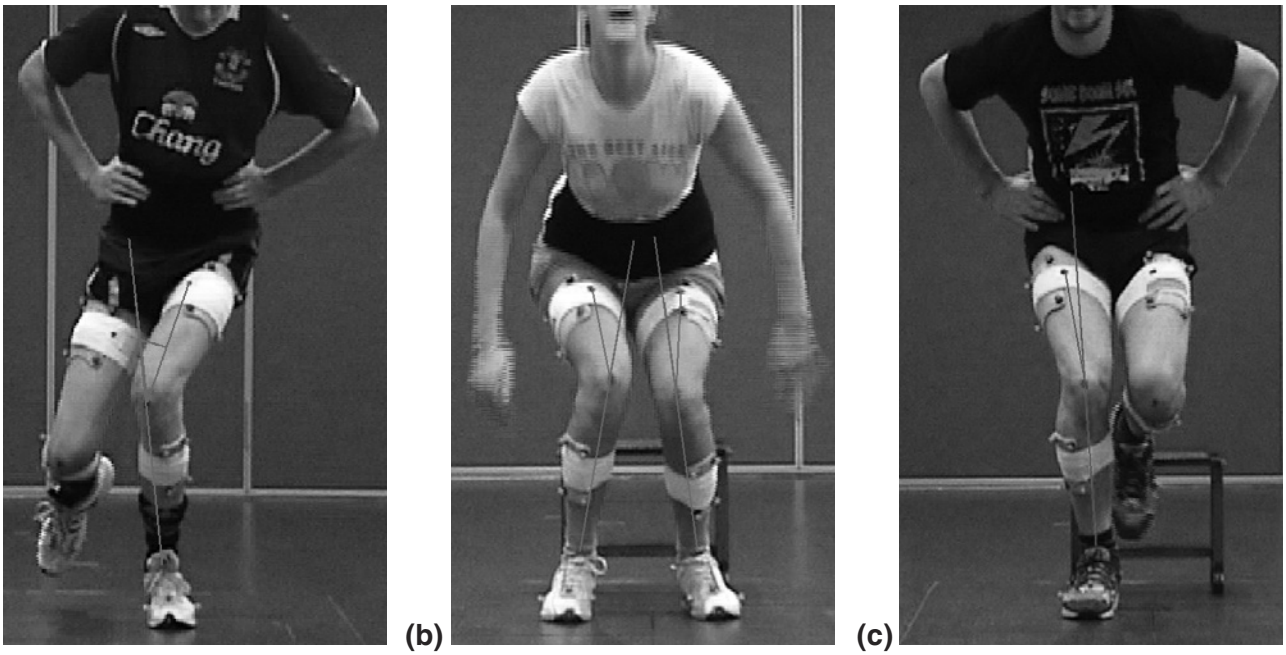

Figure 1 — Frontal-plane projection angle during (a) single-leg squat, (b) drop jump, and (c) single-leg landing.

Between-sessions reliability was good to excellent for all tests and can be seen in Table 2. ICCs ranged from .72 to .91 for women, with SLS again showing the lowest reliability, and .8 to .89 for men. SEM and SDD values can also be seen Table 2. SEM scores ranged from 2.72° to 3.22° and SDDs from 7.54° to 8.93°.

Discussion

Dynamic knee valgus during common athletic tasks has been postulated as an injury risk factor for the knee-joint complex.[3–6] Dynamic valgus can be assessed using a number of different screening tests.[4,7,11,12] Most studies to date have used 3D methods to assess lower limb kinematics. Recently, however, the use of 2D video analysis has become more common because of its greater practicality.

The validity of 2D assessment of FPPA compared with 3D analysis has previously been established,[5,13] but the reliability of the 2D technique is not well established, especially with regard to test–retest repeatability.

The main aim of the current study was to assess the reliability of 2D digital video analysis of FPPA during SLS, drop jump, and SLL. The good to excellent ICC values suggest that 2D analysis of FPPA is reliable both within and between days. Our results, coupled with those of the validity studies mentioned, suggest that this method may be used in future research, clinical and large-scale screening projects to assess lower extremity dynamic valgus in the absence of more sophisticated 3D motion analysis, with confidence. It is interesting to note that the between-days reliability of the women's SLS was higher than within-day, but ICCs can be affected by a lack of variability within scores, which may be present within test sessions more than between sessions and may account for the lower ICC.

The second aim of the current study was to explore the measurement error with the use of 2D FPPA. The SEM provides an estimate of precision of a particular measurement and consequently a range within which an individual's true score is likely to lie.[19] The SDD statistic gives an indication of the minimal change in score between tests that can be regarded as statistically significant.[18] Both the SEM and SDD are expressed in the same units as the original measurement. If these measurement error values for a specific test are known, changes between test sessions can be evaluated to determine whether any changes are true changes in individual performance or measurement error.[20] This is particularly important when assessing the effect of interventions on performance. For example, if a female athlete's 2D FPPA during the drop jump were measured before and after an intervention, we could be confident that her true score lies within 3° of the observed score on both occasions. Furthermore, if the athlete's 2D FPPA did not improve by at least 8.3° we could say that the intervention did not have a significant effect on her lower limb control during the drop-jump test.

Normative 2D FPPA values for the drop-jump and SLL tasks have been reported previously.[10] The authors of that study suggested that "average" performance resulted in values of 7° to 13° and 5° to 12° for the drop-jump and SLL tasks, respectively, in women and 3°–8° and 1°–9° in men. It was also suggested that subjects who demonstrate valgus FPPA values in excess of these normal values may be demonstrating kinematics that are detrimental and may increase the risk of injury to the patellofemoral joint or anterior cruciate ligament. Our results on healthy participants compare well to these values, with men's and women's mean SLL values of 4.69° and 7.33° and drop-jump values of –5.51° and 8.15°, respectively. Many of the male participants presented with varus angles during the drop-jump task, which may account for the 8° difference from the normative values, and although participants in both studies were recreationally active, this does not account for the type of activity in which they participate and the effect this may have on their lower limb control.

As has been discussed, 2D FPPA measurements cannot substitute for the accuracy and magnitude of 3D lower extremity joint rotations during the athletic tasks. However, they do provide a reliable and valid measure of gross lower limb kinematics in the absence of 3D measurements. Although we controlled for the minimum

Table 2 Overall Mean Values and Between-Days Intraclass Correlation Coefficients (ICC), 95% Confidence Intervals (CI), Standard Error of Measurement (SEM), and Smallest Detectable Difference (SDD) for the 3 Tests

Test	Mean	SD	ICC	95% CI	SEM	SDD
Men						
single-leg squat	8.64		.88	.82–.93	2.75	7.63
drop jump	–5.51	9.06	.89	.83–.93	3.00	8.32
single-leg landing	4.69		.80	.70–.88	2.72	7.54
Women						
single-leg squat	11.07		.72	.56–.82	3.22	8.93
drop jump	8.15	10.02	.91	.87–.95	3.01	8.34
single-leg landing	7.33		.82	.72–.88	2.85	7.90

knee-flexion angle, it is unclear whether increased knee-flexion angles affect the amount of dynamic knee valgus measured, and further investigation of this possible confounding factor is needed. Another limitation of this study is the population used. All subjects were healthy, recreationally active university students. It is unclear whether 2D FPPA may be influenced by age or by activity levels, so these results may not be applicable to elite athletes, injured, or adolescent and older age groups. Further study on other populations is required as a result. Finally, only intrarater reliability was assessed in this study; further study looking at interrater reliability is therefore required.

Although the drop-jump test has been linked to anterior cruciate ligament injury in female athletes and shown to be sensitive to changes in training,[4,9] the validity of the SLS and SLL tests with regard to injury prediction has not been studied. Two-dimensional assessment of these tests provides a simple, inexpensive, and reliable alternative for clinicians and with further validation may be useful for large-scale injury-risk screening.

Conclusion

Now that the reliability, measurement error, and validity of 2D FPPA to assess dynamic knee valgus have been established, prospective injury-risk and intervention studies should employ this method to screen participants' lower limb mechanics. Using the SEM and SDD values presented in this article, clinicians and researchers can now make informed decisions on whether changes in performance are random error or true changes in individual performance.

References

1. Starkey C. Injuries and illnesses in the National Basketball Association: a 10-year perspective. *J Athl Train*. 2000;35:161–167.
2. Hootman JM, Dick R, Agel J. Epidemiology of collegiate injuries for 15 sports: summary and recommendations for injury prevention initiatives. *J Athl Train*. 2007;42:311–319.
3. Ireland ML. Anterior cruciate ligament injury in female athletes: epidemiology. *J Athl Train*. 1999;34:150–154.
4. Hewett TE, Myer GD, Ford KR, et al. Biomechanical measures of neuromuscular control and valgus loading of the knee predict anterior cruciate ligament injury risk in female athletes: a prospective study. *Am J Sports Med*. 2005;33:492–501.
5. Willson JD, Davis IS. Utility of the frontal plane projection angle in females with patellofemoral pain. *J Orthop Sports Phys Ther*. 2008;38:606–615.
6. Souza RB, Powers CM. Differences in hip kinematics, muscle strength, and muscle activation between subjects with and without patellofemoral pain. *J Orthop Sports Phys Ther*. 2009;39:12–19.
7. Willson JD, Ireland ML, Davis I. Core strength and lower extremity alignment during single leg squats. *Med Sci Sports Exerc*. 2006;38:945–952.
8. Zeller BL, McCrory JL, Kibler WB, Uhl TL. Differences in kinematics and electromyographic activity between men and women during the single-legged squat. *Am J Sports Med*. 2003;31:449–456.
9. Noyes FR, Barber-Westin SD, Fleckenstein C, Walsh C, West J. The drop-jump screening test: difference in lower limb control by gender and effect of neuromuscular training in female athletes. *Am J Sports Med*. 2005;33:197–207.
10. Herrington L, Munro A. Drop jump landing knee valgus angle; normative data in a physically active population. *Phys Ther Sport*. In press.
11. Decker MJ, Torry MR, Wyland DJ, Sterett WI, Richard Steadman J. Gender differences in lower extremity kinematics, kinetics and energy absorption during landing. *Clin Biomech (Bristol, Avon)*. 2003;18:662–669.
12. Lawrence RK III, Kernozek TW, Miller EJ, Torry MR, Reuteman P. Influences of hip external rotation strength on knee mechanics during single-leg drop landings in females. *Clin Biomech (Bristol, Avon)*. 2008;23:806–813.
13. McLean SG, Walker K, Ford KR, Myer GD, Hewett TE, van den Bogert AJ. Evaluation of a two dimensional analysis method as a screening and evaluation tool for anterior cruciate ligament injury. *Br J Sports Med*. 2005;39:355–362.
14. Onate J, Cortes N, Welch C, Van Lunen B. Expert versus novice interrater reliability and criterion validity of the Landing Error Scoring System. *J Sport Rehabil*. 2010;19:41–56.
15. Rankin G, Stokes M. Reliability of assessment tools in rehabilitation: an illustration of appropriate statistical analyses. *Clin Rehabil*. 1998;12:187–199.
16. Coppieters M, Stappaerts K, Janssens K, Jull G. Reliability of detecting 'onset of pain' and 'submaximal pain' during neural provocation testing of the upper quadrant. *Physiother Res Int*. 2002;7:146–156.
17. Thomas JR, Nelson JK, Silverman SJ. *Research Methods in Physical Activity*. Champaign, IL: Human Kinetics; 2005.
18. Kropmans TJB, Dijkstra PU, Stegenga B, Stewart R, de Bont LGM. Smallest detectable difference in outcome variables related to painful restriction of the temporomandibular joint. *J Dent Res*. 1999;78:784–789.
19. Denegar CR, Ball DW. Assessing reliability and precision of measurement: an introduction to intraclass correlation and standard error of measurement. *J Sport Rehabil*. 1993;2:35–42.
20. Fletcher JP, Bandy WD. Intrarater reliability of CROM measurement of cervical spine active range of motion in persons with and without neck pain. *J Orthop Sports Phys Ther*. 2008;38:640–645.