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Single-leg squat as a tool to evaluate young athletes' frontal plane knee control

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ABSTRACT

Objective: To determine the agreement between 2D video analysis and subjective visual assessment by a physiotherapist in evaluating young athletes' knee control, and to determine the intra- and inter-rater reliability of the single-leg squat test.

Design: Frontal plane knee control was assessed by a physiotherapist on a three-point scale. Frontal plane projection angles were calculated from video images. To determine the intra-rater reliability, a physiotherapist re-assessed 60 subjects' performances from a video. For the inter-rater reliability, 20 subjects were assessed by both the physiotherapist and a non-experienced tester. The study continued for three test years.

Setting: Research institute.

Participants: 378 floorball, basketball, ice hockey and volleyball players.

Assessment of variables: Knee control was assessed to be good, reduced or poor.

Main outcome measures: Agreement between the video analysis and subjectively assessed frontal plane knee control. Intra- and inter-rater reliability.

Results: There were statistically significant differences in the mean frontal plane knee angles between subjects rated as having 'good', 'reduced' or 'poor' knee control. Intra-rater reliability was fair for the assessments in the first year, moderate (dominant leg) and good (non-dominant leg) for the second year, and very good (dominant leg) and good (non-dominant leg) for the third year. Inter-rater reliability was fair/poor.

Conclusions: This study suggests that by using the subjective assessment of the single-leg squat task, it is possible to detect differences in frontal plane knee control in young team sport athletes. The assessment can be considered to be reliable for clinical use when performed by an experienced tester.

Keywords: knee, physiotherapist, evaluation, screening, reliability

INTRODUCTION

Anterior Cruciate Ligament (ACL) injury will often have major consequences in an athlete's life, such as temporary and permanent disability, long-term pain, functional limitations, and absence from school, work or sports (1-3). Post-operative rehabilitation of an ACL injury takes several months and even though many athletes can return to their sport, they return with a higher risk of both re-injury and early retirement from sports (3,4). Furthermore, an ACL injury will also increase the risk of knee instability, meniscus rupture and knee osteoarthritis later in life (5).

In team sports, most ACL injuries occur without player-to-player contact (6-9). Video studies of handball and basketball suggest that the knee valgus collapse may play an important role in ACL rupture (10,11). The dynamic knee valgus is often a combination of knee valgus, hip internal rotation and adduction, tibial rotation and anterior translation, and ankle eversion (12). In a previous study, knee valgus angles and moments have been identified as the primary predictors of ACL injury (13). Individuals with greater strength in hip abductors, knee flexors and knee extensors demonstrate a lower amount of knee valgus in a single-leg squat task (14).

Neuromuscular training programs (which include balance and body control training, strengthening and agility exercises, stretching and running, and cutting and landing techniques) can be effective in reducing the injury incidence among athletes in pivoting sports such as basketball, soccer, team handball and floorball (15-20). It is recommended that programs planned to enhance knee control should focus on avoiding valgus motion. Athletes who demonstrate poor knee control might benefit more from neuromuscular training (21). To screen athletes with poor dynamic knee stability, it is important to test the reliability and validate simple field tests used for screening purposes.

The single-leg squat test is used to screen athletes for poor knee control, for example in pre-participation physical examinations (22). The single-leg squat test simulates an athletic position that requires control of the body over a planted leg that is common in pivoting ball games (23). The visual analysis of knee control during single-leg tasks is used to assess lower limb neuromuscular control (24). Subjective assessment of the single-leg squat performed by a physiotherapist has been found to be a useful screening tool among elite-level and national team handball players (25). In this study, our aim was to find out if this test procedure could also be used reliably among young team sport athletes.

The aim of this study was to determine the agreement between 2D video analysis and subjective visual assessment by a physiotherapist in evaluating knee control among young basketball, floorball, ice hockey and volleyball players. The second aim was to determine the intra-rater reliability of the subjective assessment. Finally, we wanted to determine the inter-rater reliability of the subjective assessment of knee control between a physiotherapist and a non-experienced tester.

METHODS

The single-leg squat test was part of baseline measurements in a prospective cohort study. In this study, one single physiotherapist (I.L.) tested 378 floorball, basketball, ice hockey and volleyball players, out of which 249 were female and 129 were male. The basic characteristics of the subjects and number of subjects from each of the four sports are presented in Table 1.

Subjects participated in the single-leg squat test in spring 2011, spring 2012 or spring 2013. If the subject participated in the test during more than one test period, only the first test was included in the study. Thirteen subjects were unable to name their dominant leg and two subjects were unable to perform the test on their dominant leg due to injury. Subjects' height and weight were measured and the dominant leg was assessed by asking which leg they would

use for take-off in a jump. Participants wore shorts and indoor shoes; female subjects also wore sport tops.

To determine the inter-rater reliability of the subjective assessment between a physiotherapist and a non-experienced tester, we had an inter-rater reliability group of 100 basketball and floorball players who were assessed by the non-experienced tester. This group was formed by randomly dividing the subjects entering the study in 2013 into two groups: the study group and the inter-rater reliability group.

Measurements

The single-leg squat test procedure used in this study is based on the procedure used by Stensrud et al. (25). First, small pieces of sports tape were attached to the left and right anterior superior iliac spine and tuberositas tibiae. All subjects performed 2 x 8 repetitions of two-legged squats and 2 x 5 repetitions of two-legged jumps as a warm-up. A small alteration was made to the original warm-up by leaving out the calf stretches. To standardize the knee flexion angle to 90°, subjects performed a two-legged squat down to 90° of knsee flexion. This was measured with a plastic goniometer (Baseline, USA). While the subject was holding this position, a thin rope with a small metallic object in the end was attached to the lateral side of the thigh. The length of the string was adjusted so that in a 90° knee flexion angle, the metallic object was slightly touching the ground. When the subject performed a single-leg squat standing on a metal plate, they could hear the sound of the object touching the plate when they reached 90° knee flexion. All participants were allowed one practice attempt on each leg. The subjects were instructed to hold their hands at their waist and keep their eyes focused straight forward while performing the squat. The trial was deemed invalid if the other leg was held in the front or to the side or if it touched the ground, if the subject fell, if the subject moved their hands from their waist or if

the subject looked down during the trial. All subjects were asked to perform two to three valid trials.

Subjective assessment

The subject's ability to control the knee during the single-leg squat was assessed by the physiotherapist seated in front of the subject. An ordinal scale from 0 to 2 was used. The scale used here has been introduced in a previous study (25). A score of 0 is used for 'good performance' and it was given if the subject displayed no significant lateral tilt of the pelvis, no obvious valgus motion of the knee and no medial/lateral movements or shivering during the performance. A score of 1 corresponds with 'reduced knee control'. Subjects were rated 1 if they displayed some lateral tilt of the pelvis and/or slight valgus movement of the knee and/or some medial/lateral movement or shivering during a trial. Score 2 stands for 'poor performance'. Subjects scored 2 if they displayed lateral tilt of the pelvis and/or a knee moving clearly into a valgus position and/or clear medial/lateral movements of the knee. The subjects were scored by their poorest performance: If only one of the two to three valid trials were assessed as 'poor knee control', the performance was rated 2.

Video analysis

Frontal plane knee angles were assessed for each valid trial. The trials were recorded by the physiotherapist with a digital video camera (HXR-NX70E, Sony, Japan) placed 4.5 meters in front of the metal plate. The video images were analyzed using Java-based computer software (ImageJ, National Institutes of Health, USA). Video analyses were performed by a single researcher (A.R.). From the video image, the greatest knee flexion angle was identified by assessing the subject's lowest pelvis height during the trial. The frontal plane knee angles were then estimated by marking the estimated ankle, knee and hip joint centers in the image. The mean frontal plane knee angle was calculated from the two to three valid trials for each leg.

Intra-rater and inter-rater reliability of the subjective assessment

Since this study was carried out over three years, the intra-rater reliability was assessed separately for each study year. A sample of 20 subjects per test year was randomly drawn from the video database by a statistician (K.T.), who was not involved in the assessments. These 60 performances were evaluated again by the physiotherapist six months after the third test period had ended. The physiotherapist viewed each performance once from the video recording and rated them using the same ordinal scale used in the initial assessment.

Prior to the study, the physiotherapist trained the non-experienced tester to perform the assessments. First, they went through the written instructions of the test. Secondly, they viewed video recordings of ten subjects, compared their assessments and discussed them. Thirdly, the non-experienced tester assessed performances of 15 subjects simultaneously with the physiotherapist, and the assessments were compared and discussed.

To determine the inter-rater reliability, 20 randomly drawn subjects were assessed by both the non-experienced tester and the physiotherapist. During the third test year, the new subjects entering the study were randomly put in the study group or the inter-rater reliability group. Subjects in the study group were tested by the physiotherapist and subjects in the inter-rater reliability group were tested by the non-experienced tester. The non-experienced tester performed the subjective assessment for 100 subjects. The random sample of 20 subjects was randomly drawn from these subjects. The physiotherapist used the video recordings and viewed the performances of the 20 random subjects once on a 22-inch screen and rated the performances.

Statistical methods

Statistical analyses were performed using SPSS software (IBM SPSS Statistics Version 21 for Windows). One-way ANOVA was used to compare the mean frontal plane knee angles between

the subjectively assessed groups. Cohen's kappa test was used to determine the intra-rater and inter-rater reliabilities. Kappa values were defined to be poor if kappa was < 0.20, fair for values 0.21–0.40, moderate for 0.41–0.60, good for 0.61–0.80 and very good for 0.81–1.00 (26). Spearman's rank correlation coefficient was used to determine the correlation between the subjective assessment of knee control with the scale of 'good', 'reduced' or 'poor' and the mean frontal plane projection angle (FPPA) measured from the video. A p value < 0.05 was considered statistically significant.

Ethical considerations

All subjects provided written informed consent when entering the study. For subjects younger than 18 years, consent was sought from the legal guardian. The study was approved by the Ethics Committee of Pirkanmaa Hospital District (ETL-code R10169).

RESULTS

Correlation between the FPPAs and subjective assessment

Mean FPPAs measured from the video for the dominant leg for subjects rated 'good', 'reduced' or 'poor' were 2°, 8° and 19° respectively ($p<0.001$). For the non-dominant leg, mean angles were 1°, 7° and 18° respectively ($p<0.001$). The mean FPPAs are presented in Table 2. Spearman rank correlation coefficients evaluating the association between the subjective assessment and the FPPAs were 0.64 ($p<0.001$) for the dominant leg and 0.63 for the non-dominant leg ($p<0.001$).

Intra-rater reliability for the subjective assessment

The kappa values for the agreement between the physiotherapist's initial assessment and the assessment made using the video recordings were 0.28 (fair) for the dominant leg and 0.29 (fair) for the non-dominant leg for the random sample of 20 subjects from the first test year (Table

3). For the second year sample, the values were 0.60 (moderate) for the dominant leg and 0.64 (good) for the non-dominant leg. For the third year sample, values were 0.89 (very good) for the dominant leg and 0.78 (good) for the non-dominant leg.

Inter-rater reliability for the subjective assessment

Kappa values for the agreement between the assessments by the physiotherapist and the non-experienced tester were 0.32 (fair, p=0.06) for the dominant leg (Table 4) and 0.16 (poor, p=0.35) for the non-dominant leg (Table 5).

DISCUSSION

The aim of this study was to determine the agreements between 2D video analysis of FPPAs and subjective knee control assessment performed by a physiotherapist. In addition, we wanted to determine the intra-rater reliability of the subjective assessment and the inter-rater reliability between a physiotherapist and a non-experienced tester.

We found that using the subjective assessment of the single-leg squat, it is possible to detect differences in the frontal plane knee angles. The mean FPPAs measured from the video images were statistically different between the subjects rated as ‘good’, ‘reduced’ or ‘poor’ in the physiotherapist’s subjective visual assessment.

We also noticed an improvement in the physiotherapist’s ability to detect the differences in knee control during the three-year test period. Kappa values for the intra-rater reliability increased from fair in the first year to very good (dominant leg) and good (non-dominant leg) in the third year. We have estimated that during the first test year, the physiotherapist viewed over 1,000 single-leg squats (each subject performing two to three trials per leg and practice attempts), and the intra-rater reliability for the first year was fair. After the second test year, the physiotherapist had viewed over 2,000 single-leg squats and the intra-rater reliability was moderate/good. Based on this, we could make an estimate that for the non-experienced tester

to become experienced enough for the intra-rater reliability to rise to moderate, they need to view and assess over 2,000 single-leg squats. This estimation is based on the data from one physiotherapist, which can be considered a limitation to this study.

We were interested in finding out how well the subjective assessment could be done by a non-experienced tester. The aim was to get information about how well this test could be executed by a person without a physiotherapy degree, for example a coach or an athletics trainer working with young athletes. The inter-rater reliability between the physiotherapist and the non-experienced tester was fair for the dominant leg and poor for the non-dominant leg. Our findings differ from those of a previous study, which concluded that both physiotherapists and inexperienced physiotherapy students can reliably assess the single-leg squat on a ten-point scale (27).

Previous studies with different single-leg squat procedures have been conducted to assess the reliability of the test. The agreement between a physiotherapist and a consensus panel consisting of five clinicians was found to be excellent or substantial depending on the experience level of the physiotherapist (24). When a physiotherapist performed two ratings with a week in between, both times using a video image, the agreement varied from excellent to substantial, again depending on the experience level (24). In a study using a single-leg squat to 60° knee flexion, two investigators rated separately hip adduction and knee valgus during the task. For knee valgus assessment, sensitivity was low to moderate and specificity was moderate to high (28). It seems that the tester's experience level plays an important role when performing the subjective assessment. This is important to consider when introducing the test for screening use in the field.

A study among Norwegian handball players indicates that the visual assessment of the single-leg squat may be a helpful tool when screening for poor knee control among elite-level athletes

(25). The test-retest reliability of single-leg squats was fair for the right leg and moderate for the left leg. The tests were done during the same day so the retest took place after the subjects had performed several maximal strength tests. Consequently, fatigue might have influenced performance in the second test. The intra-rater reliability for the 2D video analysis was assessed in the same study (25). The knee angle difference in measurements done 30 days apart by the same tester was 3.3° (SD 2.9).

In all the subjectively assessed groups, both varus and valgus angles were detected. When assessing the knee control, the observer did not only assess the valgus motion of the knee, but also the medial/lateral movement and shivering. In the greatest knee flexion angle, the knee can be in a varus angle, but during the performance there is clear medial/lateral movement. The subject is assessed as having reduced knee control, but from the video image a very small FPPA is detected. In this study, the FPPA was calculated at the point of the greatest knee flexion angle. This is not necessarily the point of the greatest FPPA, and this can be considered as a limitation to the study. Subjects often demonstrated quite a lot of medial/lateral movement of the knee when descending to the squat but the maximal knee valgus angle can be part of the ascending phase.

In this study, we did not verify the maximal knee flexion angle with an additional video camera. In most cases, the subjects lowered themselves to the squat slowly and began to ascend as soon as they heard the object touching the metal plate. In some cases, subjects performed the single-leg squat task quite fast so that by the time they heard the sound, the knee flexion angle was slightly smaller than 90°. This could be considered as a limitation to the study.

As mentioned earlier, dynamic knee valgus is a multiplanar motion. In this study, we focused on the frontal plane motion of the knee to allow for easier assessment in the field setting. In the

future, we will study if observing and measuring the frontal plane motion is enough to detect the athletes at greater risk of injury.

Conclusions

This study suggests that the subjective assessment of knee control during a single-leg squat task is a suitable tool to screen for athletes with reduced knee control among young team sport athletes, when performed by an experienced tester. In future analyses, we will examine whether those athletes assessed as having poor or reduced control are at greater risk of knee injury.

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Table 1. Basic characteristics of subjects and number of participants by sport

Characteristic	Females (n=249)	Males (n=129)
	mean (SD)	mean (SD)
Age (years)	18 (4)	17 (2)
Height (cm)	168 (7)	179 (8)
Weight (kg)	63 (8)	70 (10)
BMI	22 (2)	22 (3)
Sport	n	n
Floorball	95	70
Basketball	78	59
Ice hockey	58	-
Volleyball	18	-

Table 2. The distribution of athletes in the subjectively assessed groups and the corresponding frontal plane projection angles (°) measured from the video analysis

	Subjective assessment			
a) dominant leg	Good	Reduced	Poor	
Number of athletes (%)	35 (10)	175 (48)	153 (42)	
Measured angles				
Mean (SD)	2.2 (7.3)	7.9 (7.6)	18.7 (8.1)	*
Median	2.5	7.6	18.6	
Range	-10.1 to 20.2	-16.2 to 31.0	-4.0 to 56.9	
b) non-dominant leg				
Number of athletes (%)	33 (9)	173 (47)	159 (44)	
Measured angles				
Mean (SD)	1.2 (6.4)	7.5 (6.5)	18.1 (8.7)	*
Median	1.0	8.1	19.0	
Range	-14.1 to 15.2	-13.8 to 24.1	-6.0 to 38.8	

* $p<0.001$

Table 3. Kappa values for agreement between the physiotherapist's initial assessment and re-assessment (intra-rater reliability)

Test year	Dominant leg		Non-dominant leg	
	Kappa	p-value	Kappa	p-value
1st	0.28	0.06	0.29	0.06
2nd	0.60	<0.01	0.64	<0.001
3rd	0.89	<0.001	0.78	<0.001
All years	0.58	<0.001	0.58	<0.001

Table 4. The agreement between the physiotherapist's and non-experienced tester's assessment of knee control of the dominant leg

Dominant leg	Physiotherapist			
Non-experienced tester	Good	Reduced	Poor	Total
Good	0	0	0	0
Reduced	0	5	0	5
Poor	0	7	6	13
Total	0	12	6	18

Cohen's kappa 0.32, p=0.06

Table 5. The agreement between the physiotherapist's and non-experienced tester's assessment of knee control of the non-dominant leg

Non-dominant leg	Physiotherapist			
Non-experienced tester	Good	Reduced	Poor	Total
Good	0	0	0	0
Reduced	1	2	6	9
Poor	0	1	8	9
Total	1	3	14	18

Cohen's kappa 0.16, p=0.35