Physiotherapists Can Identify Female Football Players With High Knee Valgus Angles During Vertical Drop Jumps Using Real-Time Observational Screening

EXcessive knee valgus motion has been identified as contributing to noncontact anterior cruciate ligament (ACL) injuries\(^1\,\(^2\,\) and is visually associated with a medial collapse of the knee during dynamic tasks. Greater knee valgus angles, side-to-side differences in knee valgus,\(^2\,\) and lower hip and knee flexion angles\(^2\) have been reported to be more common in females compared to males. In addition, females exhibit higher external knee abduction moments compared to males during vertical drop-jump landing, with greater differences observed during pubertal growth.\(^3\) This may in part explain the higher ACL injury incidence documented in female athletes.\(^2\,\)\(^2\,\)\(^3\,\)\(^2\,\)\(^2\) Furthermore, 1 prospective study\(^4\) reported that high dynamic knee valgus and knee abduction moments were predictive of ACL injury in female athletes.

To identify female athletes at risk for ACL injury and to facilitate targeted injury-prevention programs, there is a need for standardized, time-efficient, and low-cost assessment methods. Such methods should be easy to use and to implement for large-scale screening, and at the same time provide valid and reliable data. Although 3-D motion analysis is considered the gold standard method to assess knee kinematics and kinetics, this approach is not suitable for large-scale screening of athletes.\(^2\) As a consequence, several investigators have sought to develop more

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simplistic screening methods.\textsuperscript{10,21,24,25} For example, the assessment of frontal plane knee motion using 2-dimensional video (2-D) during a drop-jump landing task is commonly used clinically. The relationship between 3-D motion analysis and 2-D video reviews of vertical drop jumps has been evaluated, with moderate to good correlations reported.\textsuperscript{10,22,24} Other studies have attempted to develop clinic-based algorithms to predict high knee abduction moments during drop-jump landings.\textsuperscript{23-27}

Real-time observational screening represents an easy and low-cost method for assessing knee valgus during a drop-jump task. However, reliable visual criteria are necessary to standardize ratings and to ensure adequate reliability. The reliability of visual assessments of frontal plane knee motion using 2-D video recordings has been investigated during single-leg squats\textsuperscript{1,2} and vertical drop jumps,\textsuperscript{21,24} with varying results. For single-leg squats, the percentage agreement between raters has been reported to be 41\% to 96\%, with kappa coefficients ranging from 0.00 to 0.92. Higher agreement has been found for vertical drop-jump assessments, with agreement of 88\% to 93\% and corresponding kappa coefficients of 0.75 to 0.85 in 1 study\textsuperscript{20} and intraclass correlation coefficients of 0.89 and 0.92 in another.\textsuperscript{24} However, the drop-jump assessments in these studies were based on video reviews, and only 1 study\textsuperscript{27} has investigated real-time assessment of knee kinematics during a vertical drop-jump task. Stensrud et al\textsuperscript{31} reported good agreement between real-time visual evaluation of knee control during a vertical drop-jump landing task and 2-D video analysis of knee valgus. Although high intrarater agreement of the real-time assessment was reported by Stensrud et al,\textsuperscript{31} neither the interrater reliability of the real-time assessment nor the relationship among 3-D kinematics and kinetics was investigated.

The purpose of the current study was to assess the relationships among real-time observational screening of frontal plane knee valgus and actual knee valgus angles and abduction moments calculated from 3-D motion analysis during a vertical drop-jump landing task. A second purpose was to investigate the interrater agreement of 3 physiotherapists using real-time observational screening. We hypothesized that participants rated as having poor frontal plane knee control, as determined by observational screening, would display higher valgus angles and moments than participants rated as having good control.

**METHODS**

**Study Design and Participants**

We invited all players in the Norwegian female elite football (soccer) league (Toppserien) to participate in a series of baseline screening tests as part of a prospective cohort study investigating risk factors for non-contact ACL injuries. Players who were expected to play in the elite league during the 2009 competitive football season were eligible for participation. To be included in the study, the participants had to be free of any lower extremity injury that prevented them from full participation in football training and match play at the time of testing. A total of 77 participants volunteered to participate; however, only 60 completed all phases of data collection (mean ± SD age, 23 ± 5 years; height, 166 ± 5 cm; body weight, 63 ± 7 kg). Prior to participation, informed consent was obtained from all participants. The study was approved by the Regional Committee for Medical Research Ethics, South-Eastern Norway Regional Health Authority, and by the Norwegian Social Science Data Services.

**Real-Time Observational Screening**

To assess frontal plane knee control, participants performed a vertical drop-jump task from a 30-cm box (Figure 1A).\textsuperscript{14} The participants wore shorts, a sports bra, and indoor training shoes. Prior to performing the drop-jump task, the anterior superior iliac spines and the tibial tuberosities were marked with small pieces of sports tape. Participants performed a standardized warm-up procedure consisting of squats (2 sets of 8 repetitions), maximal vertical jumps (2 sets of 5 repetitions), and calf stretching (stretch duration, 2-3 minutes).

Participants were instructed to step off the box using a 2-foot landing strategy, immediately followed by a maximal vertical jump. To ensure that maximal effort was achieved, participants were encouraged to touch a football hanging from a string 260 cm above the floor. A trial was considered invalid if the participants jumped off the box or failed to perform a vertical jump after the first landing. Participants were allowed up to 3 practice trials prior to testing. Participants completed 3 valid trials, and the trial that scored the lowest with respect to knee control was used for analysis.

The participants’ ability to control their knees in the frontal plane during the landing phase of the drop-jump task was assessed using a graded scoring scale ranging from 0 to 2.\textsuperscript{14} A score of 0 corresponded to good control, in which the participant displayed proper knee alignment, with a straight line from the knees to the mid toes, no obvious valgus motion of either of the knees, and no mediolateral side-to-side movement of the
knee during the performance. The score of 1 corresponded to reduced control and indicated improper alignment, with 1 or both knees moving into a slight valgus position and/or some mediolateral side-to-side movement during the performance. A score of 2 corresponded to poor control and was given when the alignment of the knees was poor, with at least 1 of the knees clearly moving into a substantial amount of valgus (ie, knee medial to foot) and/or clear mediolateral side-to-side movement of the knee.

Three sports physiotherapists independently and simultaneously assessed frontal plane knee control during the landing phase of the drop-jump task, according to the criteria outlined above. One had 5 years of clinical experience as a physiotherapist working with athletes with musculoskeletal disorders. The other 2 had 20 and 15 years, respectively, of experience as sports physiotherapists. All 3 physiotherapists were familiar with the drop-jump task and routinely used this test when screening athletes. In addition to each independent assessment, a rater-consensus score for each participant was established as the score given by at least 2 of the 3 raters. Consensus was reached for all 60 cases.

During testing, the raters were positioned 3 m in front of the 30-cm box and scored each participant while blinded to the scores of the other raters. No discussion was allowed between the raters during the scoring of the participants. The rating forms were collected by the project coordinator at the end of the testing session to maintain blinders on the results. The raters were also blinded to the results of the 3-D motion analysis (see below for details), and the participants were blinded to their scores.

To ensure scoring consistency, the raters received standardized rating instructions and practice prior to the actual testing. This included detailed written information on the testing procedures, as well as group and individual training sessions using photographs and videos of examples of knee control during vertical drop jumps. Each physiotherapist screened approximately 30 players during 2 days of training.

Three-Dimensional Motion Analysis
To obtain 3-D knee joint kinematics and kinetic data, participants performed an additional vertical drop-jump task from a 30-cm box in a motion analysis laboratory under conditions similar to those of the real-time visual assessment (with the exception of the hanging football to encourage jump performance) (FIGURE 1B). Eight infrared cameras (ProReflex; Qualisys AB, Gothenburg, Sweden) were used to capture kinematic data at 240 Hz, while ground reaction forces and the center-of-pressure data were recorded from 2 force platforms collecting at 960 Hz (LG6-4-1000; Advanced Mechanical Technology, Inc, Watertown, MA). Prior to performing the drop-jump task, participants completed a static calibration trial to determine the anatomical segment coordinate systems. To estimate body-segment parameters, anthropometric measures of all participants were obtained, including 46 measures of segment lengths, circumferences, and widths.

Thirty-five reflective markers were attached over anatomical landmarks on the legs, arms, and torso (FIGURE 2). One research assistant palpated the anatomical landmarks and placed the markers on all participants to ensure standardization. Participants were allowed up to 3 practice trials, and at least 3 successful trials were collected. For a trial to be considered successful, the participants had to land with 1 foot on each of the 2 adjacent force platforms, and all reflective markers had to be visible to the cameras throughout the task.

Marker trajectories were identified with the Qualisys Track Manager (Qualisys AB). Motion and force data were filtered using a 15-Hz smoothing spline. The contact phase consisted of the time from initial contact to toe-off and was defined as the period when the unfiltered vertical ground reaction force exceeded 20 N. Knee valgus angles and abduction moments were obtained using custom MATLAB scripts (The MathWorks, Inc, Natick, MA). External knee joint moments were calculated using inverse dynamic equations.

Peak knee valgus angles and external knee abduction moments during the contact phase of the drop-jump task were the variables of interest. Using the average for the right and left knees, the jump with the highest valgus angles out of the 3 trials for all participants was chosen, as this jump reflected the worst trial for the participant and better corresponded to the procedures used during the real-time observational screening.

Statistical Analysis
Statistical analyses were performed using SPSS for Windows Version 18 (SPSS
Inc, Chicago, IL). Using the consensus scores, differences in knee valgus angles and abduction moments between the groups rated as having good, reduced, and poor knee control were determined using 1-way analyses of variance. Post hoc testing consisted of the Tukey honestly significant difference test. The Spearman rank correlation coefficient was used to assess the association among the classification of participants from the observational screening test scores (independent categorical variable) and knee valgus angles and abduction moments (dependent continuous variables). This analysis was performed for each of the raters, as well as for the rater consensus scores. Correlation coefficients of 0.81 to 1.00 were interpreted as being very good, 0.61 to 0.80 as good, 0.41 to 0.60 as moderate, 0.21 to 0.40 as fair, and less than 0.20 as poor. 3

The ability of each rater to identify participants with the highest knee valgus angles and abduction moments was assessed with receiver-operating-characteristic (ROC) curves. The area under the curve, with 95% confidence intervals, was calculated for the 3 raters. Values for the ROC range between 1.0 (perfect separation of the test values) and 0.5 (no apparent distributional difference), and describe the discriminative ability of a test. 36

Interrater agreement among the 3 physiotherapists was assessed by calculating kappa coefficients for paired assessments. 36,37,38 The kappa coefficient is based on the percentage agreement between raters and corrects for agreement expected by chance. Kappa coefficients were interpreted as follows: 0.81 to 1.00, almost perfect agreement; 0.61 to 0.80, substantial agreement; 0.41 to 0.60, moderate agreement; 0.21 to 0.40, fair agreement; 0.01 to 0.20, slight agreement. Coefficients less than or equal to 0.01 indicated poor agreement. 39

For all analyses, we considered an alpha level of .05 or less as being statistically significant.

RESULTS

A summary of the rating scores of knee control, as determined by the 3 physiotherapists, is presented in Table 1. Based on the rater consensus, half of the participants were rated as having good frontal plane knee control, whereas 33% and 15% were rated with reduced and poor control, respectively.

Knee Valgus Angles

The analysis of variance comparing knee valgus angles across groups was significant (P<.001) (Figure 3). Post hoc testing revealed that participants rated with poor knee control had higher mean ± SD knee valgus angles compared to participants with good control (10.3° ± 3.4° versus 1.9° ± 4.3°). Furthermore, participants rated as having reduced knee control (5.4° ± 4.1°) differed from the groups rated as good and poor control.

The correlation between the real-time observational screening test scores and knee valgus angles was moderate for all 3 raters, as well as for the rater consensus (correlation coefficients ranging from 0.54 to 0.60, P≤.001) (Table 2). Based on the ROC curves, the ability to identify participants with high knee valgus angles using real-time observational screening was very good across all raters (Table 3).

Knee Abduction Moments

The analysis of variance comparing peak knee abduction moments for participants rated with good, reduced, and poor knee control was not significant (P=.20) (Figure 4). In addition, the correlations between peak knee abduction moments and the real-time observational screening test scores were not significant (Table 2). Based on the ROC curves, the ability to identify participants with high peak knee abduction moments using real-time observational screening was moderate across all raters (Table 3).

The interrater agreement among the physiotherapists with respect to classifying participants as having good, reduced, or poor knee control was substantial to almost perfect. Percentage agreement and kappa coefficients ranged from 70% to 95% and 0.52 to 0.92, respectively (Table 4).

DISCUSSION

The results of the current study suggest that participants with high knee valgus angles during a vertical
drop-jump landing task can be identified using real-time observational screening. Our findings support the hypothesis that participants scored as having poor or reduced knee control would display higher knee valgus angles than participants scored as having good knee control, and that the observational screening test scores would be correlated to the knee valgus angles. However, the observational screening was not capable of identifying participants with high peak abduction moments. Our findings also indicate that real-time observational scores are consistent among physiotherapists who receive rating instructions and training in scoring knee control.

There were significant differences in peak knee valgus angles between participants rated as having good, reduced, and poor knee control. Furthermore, the observational classifications correlated moderately with the objectively measured valgus angles. Moreover, our results revealed that the observational screening test had a discriminating accuracy (area under the curve) of 0.85 to 0.89 for all 3 raters, with respect to identifying high valgus angles and distinguishing players with poor knee control. Our findings suggest that real-time observational screening may be useful for identifying athletes who would benefit from injury-prevention training.

Our findings are consistent with a previously published study of a cohort of elite handball players that compared observational screening scores to valgus angles measured with 2-D frontal plane video analysis. These authors used the same scoring system as that of the current study, and found good agreement between the subjective assessment of players with poor knee control and valgus angles measured from frontal plane video. Similar to our study, Ekegren et al compared observational evaluations of frontal plane knee control during a drop-jump landing to valgus angles measured with 3-D motion analysis, and reported substantial specificity (60%-72%) but inadequate sensitivity (67%-87%). These authors defined athletes with valgus angles above 10.8° as high-risk individuals who were more likely to experience an injury. Interestingly, this value corresponded closely to the valgus angles for participants displaying poor control in the current study. Another study compared the frontal plane projection angle and knee separation distance measured from 2-D video recordings and 3-D motion analysis and reported intraclass correlation coefficients of 0.89 to 0.97, demonstrating higher agreement than that reported in the current study. This is logical, as video analysis permits a more standardized and detailed assessment than real-time observational screening.

On average, the mean peak knee abduction moments of the participants in our study were relatively low (0.33 Nm/kg); however, considerable variability was observed (range, 0.08-0.60 Nm/kg). There was no correlation between the subjective classification of participants’ knee control and objective measures of knee abduction moments for any of the raters. This finding was further confirmed by the poor discriminative accuracy with respect to the knee moments, with area-under-the-curve values at or below 0.57 for all 3 raters. This suggests that real-time observational screening cannot be used to identify those individuals with high knee abduction moments during a vertical drop-jump task. Furthermore, a post hoc analysis revealed that the correlation between knee valgus angles and abduction moments was not statistically significant.

### TABLE 2

<table>
<thead>
<tr>
<th>Rater</th>
<th>Valgus Angle Correlations</th>
<th>P Value</th>
<th>Abduction Moment Correlations</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.58 (0.37, 0.74)</td>
<td>&lt;.001</td>
<td>0.11 (0.16, 0.35)</td>
<td>.40</td>
</tr>
<tr>
<td>2</td>
<td>0.54 (0.34, 0.70)</td>
<td>&lt;.001</td>
<td>0.11 (0.15, 0.34)</td>
<td>.39</td>
</tr>
<tr>
<td>3</td>
<td>0.60 (0.41, 0.75)</td>
<td>&lt;.001</td>
<td>0.09 (0.17, 0.32)</td>
<td>.49</td>
</tr>
<tr>
<td>Consensus</td>
<td>0.56 (0.34, 0.71)</td>
<td>&lt;.001</td>
<td>0.11 (0.16, 0.34)</td>
<td>.41</td>
</tr>
</tbody>
</table>

*Values in parentheses are 95% confidence interval.

### TABLE 3

<table>
<thead>
<tr>
<th>Rater</th>
<th>Valgus Angle AUC</th>
<th>P Value</th>
<th>Abduction Moment AUC</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.88 (0.73, 0.97)</td>
<td>.001</td>
<td>0.57 (0.39, 0.75)</td>
<td>.44</td>
</tr>
<tr>
<td>2</td>
<td>0.85 (0.74, 0.96)</td>
<td>.001</td>
<td>0.57 (0.40, 0.75)</td>
<td>.46</td>
</tr>
<tr>
<td>3</td>
<td>0.89 (0.80, 0.98)</td>
<td>.001</td>
<td>0.56 (0.38, 0.75)</td>
<td>.56</td>
</tr>
</tbody>
</table>

Abbreviation: AUC, area under the curve. *Values in parentheses are 95% confidence interval.
TABLE 4

<table>
<thead>
<tr>
<th>Rater</th>
<th>Agreement, %</th>
<th>Kappa Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rater 1 versus rater 2</td>
<td>72</td>
<td>0.54</td>
</tr>
<tr>
<td>Rater 1 versus rater 3</td>
<td>70</td>
<td>0.52</td>
</tr>
<tr>
<td>Rater 2 versus rater 3</td>
<td>95</td>
<td>0.92</td>
</tr>
</tbody>
</table>

Interrater Agreement for Classifying Participants as Having Good, Reduced, or Poor Knee Control

The observational screening evaluation was based on reviews of video recordings, and the rating procedures differed from the current study. These authors used a dichotomous rating scale, classifying the player either landing with the knees medial to the toes or in line with the toes, whereas the current study scored frontal plane knee control using 3 categories. Hence, differences in the rating procedures limit the ability to directly compare the level of rater agreement across studies.

A potential limitation of the current study is that the real-time observational screening and the motion analysis were not assessed simultaneously, hence 2 separate jumps were evaluated. Though the test procedures were similar, participants might have performed the 2 jumps differently. It should also be acknowledged that an overhead target was included in the screening test but not in the motion analysis lab, due to technical reasons related to the camera system. Using a ball as an overhead target in the screening test might have affected performance and resulted in a knee-motion pattern that differed from that during the 3-D motion analysis.

Even though 3-D motion analysis is considered the gold standard for assessing lower extremity kinetics and kinematics, there are several potential sources of error, including marker placement, skin movement artifacts, and joint-center estimations. These factors could affect the accuracy of the calculated joint angles and moments. Another limitation of the present study is that the valgus angles and abduction moments for the right and left knees from the 3-D analysis were averaged, which precluded the assessment of potential side-to-side differences. However, as the observational screening test was based on an overall evaluation of frontal plane knee control rather than a single-leg assessment, calculating the average values enabled a better comparison to the observational scores.

We also acknowledge that mediolateral knee motion observed by the raters represents a multiplane and multijoint pattern that not only consists of knee valgus motion but also involves ankle, knee, and hip motions in the transverse plane. The rationale for investigating frontal plane knee kinematics and kinetics is that these variables have previously been shown to predict ACL injuries in female athletes and that a valgus collapse has been identified as a part of the ACL injury mechanism. In addition, existing screening tools developed to identify knee injury risk have focused on frontal plane knee kinematics and kinetics. Although the real-time assessment of knee control appears to be promising for large-scale screening of athletes, there is a need to investigate the predictive value of such screening for knee injuries.

CONCLUSION

Physiotherapists can identify female athletes with high knee valgus angles during a vertical drop-jump landing using real-time observational screening. We found a moderate correlation between the observational screening test scores and objectively measured knee valgus angles for all 3 raters. However, the screening test scores correlated poorly with knee abduction moments. Finally, we found substantial to almost perfect interrater agreement among the 3 physiotherapists, suggesting that the observational screening test can provide reliable results when used by physiotherapists who receive training similar to that reported in this study.

KEY POINTS

- **FINDINGS:** Physiotherapists can identify female athletes with high knee valgus...
angles during a drop-jump landing task using real-time observational screening. However, the observational screening test scores did not correlate with knee abduction moments.

**IMPLICATIONS:** The screening procedures used in the current study are simple and easy to use and implement in a clinical setting, as they do not necessitate specialized equipment. Real-time assessment using a simple screening test enables large-scale screenings of athletes with the aim of identifying those at risk for knee injury.

**CAUTION:** The predictive ability of the observational screening test with respect to knee injury was not assessed in the current study.

**ACKNOWLEDGEMENTS:** The authors acknowledge all players in the Norwegian female elite football league (Topperen) for their participation in this study, and the physiotherapists (J.K., G.M., and A.F.) who participated in collecting the data. We also thank Kam-Ming Mok for his valuable help with the data processing.

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