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A Comparison of Frontal Plane Projection Angle Across Landing Tasks in Female Gymnasts

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• University of Salford

The aim of this study was to compare FPPA between three landing tasks and determine the reliability of FPPA in 15 competitive female gymnasts (age 13.5 ± 2.07 years). Reliability of FPPA was highest in the drop landing task, with no learning effect present. The backaway task showed the greatest FPPA (right: 26.75 ± 9.57°; left: 19.67 ± 9.03°), which was greater than the drop landing task (right: 19.07 ± 7.42°; left: 12.18 ± 4.83°). Individuals involved in training young female gymnasts are encouraged to screen for injury risk using FPPA during the drop landing task.

Key Words: knee valgus, sport specific, injury risk, knee

The knee joint is one of the most common sites of injury in female athletes, including anterior cruciate ligament (ACL) tears and patellofemoral pain syndrome. Such injuries generally occur through noncontact or overuse mechanisms and are therefore potentially preventable with appropriate training strategies.

A valgus or abducted position of the knee on landing is reported to be a primary predictor of ACL and patellofemoral injury. Three-dimensional (3D) motion analysis is widely recognized as the gold standard method to assess knee valgus in athletes; however, this technique is costly and time consuming and, as a result, may be unsuitable in large-scale screening programs and inaccessible to many athletes. Consequently, Wilson and Davis introduced frontal plane projection angle (FPPA) to identify dynamic knee valgus during landing tasks, establishing that FPPA has the ability to identify high-risk athletes when compared with 3D analysis. Subsequently, the assessment of FPPA during single leg squats or drop landings has now been acknowledged for its ability to effectively screen for dynamic knee valgus, which increases the risk of ACL and patellofemoral injury.

The ACL tear is the most commonly reported knee injury in gymnasts, which may be attributed to their exposure to high-frequency (~200 x week), high-load (3.9-14.4 times body mass) landings. Gymnasts are encouraged to land with minimal flexion at the knee, as this incurs point deductions in competition; however, this may add to impact force and ACL strain. However, knee valgus and FPPA have not been reported for female gymnasts, especially during gymnastic-specific tasks. The purpose of this study was to determine session internal consistency and test-retest reliability of FPPA across three different landing tasks (bilateral jump landing, tuck back somersault, and tuck backaway from asymmetric bars) and compare FPPA between tasks in female gymnasts. It was hypothesized that the backaway would demonstrate greater FPPA and variability due to a combination of the rotation of the body in flight and the height of the asymmetric bars. An additional aim was to compare FPPA between limbs, as asymmetries have been
observed in other sports, although it was hypothesized that there would be little difference between limbs due to the common bilateral landing observed within gymnastic dismounts.

**Methods**

**Participants**

Adolescent female, competitive (competed ≥ 6 times in the previous 12 months) gymnasts (n = 15, age 13.5 ± 2.07 years, height 1.54 ± 0.11 m, body mass 46.16 ± 8.2 kg) who train ~15 hr per week volunteered to participate in this study. All participants were free from lower extremity injury and had no history of knee pathology. Informed written consent was obtained from all participants, along with written consent from parents/guardians and the project was approved by the university research ethics committee.

**Instrumentation**

Using previously reported methods,15,16 FPPA was assessed across three different landing tasks (50 cm drop landing, tuck back somersault, and backaway dismount from the asymmetric bars) to permit comparisons of FPPA between tasks and between legs.

**Tasks**

Bilateral jump landing: Participants were asked to stand feet shoulder width apart on a 50 cm block, then drop off the block and land directly on a tape marker placed 30 cm in front of the block, and to stick the landing with no set instructions regarding arm movement.

Tuck back somersault: Participants were instructed to stand on a tape marker and, in their own time, perform a standing tuck back somersault, and land with two feet on a different tape marker positioned 0.5 m behind the starting position.

Tuck backaway from asymmetric bars: Participants started on the high bar, swung down past the low bar, released the high bar, and performed a backward somersault, landing bilaterally on a tape marker positioned 2 m from the bar.

**Procedures**

The landing surface for all tasks was identical (20 cm shock-absorbent landing mat) and trials were only accepted if the subject landed on both feet with no fall. All equipment used in the test complied with the safety standards as set per the International Gymnastics Federation (FIG). To familiarize participants with the tasks, each subject performed five practice trials of the three tasks as part of their warm up.

Participants performed each task three times on day one to establish internal consistency, with 60 s rest between repetitions and 120 s rest between tasks. Testing was repeated seven days later to establish test-retest reliability, with participants performing three trials of each task and the mean FPPA compared between tasks. All participants were asked to refrain from any strenuous exercise for 24 hr before testing. Participants performed tasks in bare feet, without taping or bracing of the joints.

**Assessment of FPPA**

The primary investigator placed markers at the knee joint (midpoint of the femoral condyles) and at the proximal thigh along a line from the anterior superior iliac spine to the knee marker (midpoint of the ankle malleoli), to approximate the center of the ankle joint.15,16

A digital video camera (Casio Exilim EX-F1, Tokyo, Japan) was mounted at the height of the subject's knee (individually measured from the floor to the midpoint of the patella), 2 m anterior to the landing target and aligned perpendicular to the frontal plane and calibration using a 1-m square frame. The primary investigator measured the angle at the lowest point of the landing phase, determined by maximal displacement of the marker on the patella (Figures 1 and 2) using Image J (ImageJ for Windows, 1.46R, Microsoft, Redmond, WA, USA). Assessment of FPPA involved drawing a line from the marker at the proximal thigh to the marker at the knee joint and another line from this point to the marker at the ankle joint. Positive FPPA values refer to knee valgus, and negative values reflect knee varus.15

**Statistical Analyses**

Distribution of data were assessed via Shapiro-Wilk's test of normality. Cronbach's alpha were performed to determine internal consistency with intraclass correlation coefficients (ICC) (2,3) performed to determine test-retest reliability, with > 0.7 considered to be highly reliable. Paired samples t tests were used to identify differences in FPPA between-session, using mean values from day one and two.

To identify differences in FPPA between tasks (jump landing, tuck back somersault, and tuck backaway...
Results

Within-Session Reliability

All data were normally distributed. The ICC results indicated moderate internal consistency for each task during day one (Table 1).

Test-Retest Reliability

Test-retest reliability of FPPA was high for the drop landing and tuck back somersault (0.750–0.886), although only moderately reliable for the backaway (0.500–0.619). Subsequent paired samples $t$ tests revealed small (Cohen’s $d \leq 0.30$) and nonsignificant differences ($p > .05$) in FPPA between sessions for both legs (Table 2).

Between-Task Differences

Results of the ANOVA highlighted a significant difference in FPPA ($p = .030$, power = 0.98) between tasks for the right leg, with Bonferroni post hoc analysis showing that the FPPA during the backaway ($26.75 \pm 9.57^\circ$) was significantly greater (Cohen’s $d = 0.90$, $p = .042$) when compared with the drop landing ($19.07 \pm 7.42^\circ$) (Figure 3). Similarly, for the left leg, a significant difference in FPPA ($p = .023$, power = 0.94) was identified between tasks, with the backaway ($19.67 \pm 9.03^\circ$) being significantly greater (Cohen’s $d = 1.03$, $p = .019$) than the drop landing task ($12.18 \pm 4.83^\circ$) (Figure 3). Nonsignificant but moderate differences ($p > .05$, Cohen’s $d \leq 0.59$) were observed in FPPA between the tuck back and the drop landing for both legs, with no significant differences between the tuck back and the backaway.

<table>
<thead>
<tr>
<th>Task</th>
<th>Right</th>
<th>Left</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drop landing</td>
<td>$\alpha = .690, p &lt; .001$</td>
<td>$\alpha = .619, p &lt; .001$</td>
</tr>
<tr>
<td>Tuck back somersault</td>
<td>$\alpha = .615, p &lt; .001$</td>
<td>$\alpha = .446, p &lt; .005$</td>
</tr>
<tr>
<td>Backaway</td>
<td>$\alpha = .605, p &lt; .001$</td>
<td>$\alpha = .584, p &lt; .001$</td>
</tr>
</tbody>
</table>

From the asymmetric bars, a one-way ANOVA with Bonferroni post hoc analysis was performed. In addition, dependent $t$ tests performed to compare limbs between tasks. Effect sizes were also calculated using the Cohen’s $d$ method and interpreted as small (0.2), moderate (0.5), and large (0.8).

An a priori alpha level was set to $p \leq .05$. Data analysis was conducted using SPSS for Windows (Version 20; IBM, Armonk, NY, USA), with post hoc power calculations completed using GPower3.1.22.
back and the backaway for left leg \((p = .13, \text{Cohen’s } d = 0.50)\), although a large effect size was observed for the right leg \((p = .07, \text{Cohen’s } d = 0.94)\).

**Differences Between Extremities**

During the drop landings, FPPA values for the right leg \((19.07 \pm 7.4^\circ)\) were significantly greater (Cohen’s \(d = 1.10, p = .03\)) than the left leg \((12.18 \pm 4.83^\circ)\), with similar trends for the backaway landing task (right \(26.75 \pm 9.57^\circ\); left: \(19.67 \pm 9.03^\circ\); Cohen’s \(d = 0.76, p = .038\)). In contrast, there was a small and nonsignificant difference (Cohen’s \(d = 0.22, p = .26\)) between the right and left leg during the tuck back landing task (Figure 3).

### Table 2: Test-Retest Reliability (ICC) and Comparisons (t Tests, Effect Sizes and SEM) Between Days

<table>
<thead>
<tr>
<th>Task</th>
<th>Right Leg</th>
<th></th>
<th>Left Leg</th>
<th></th>
</tr>
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<tbody>
<tr>
<td></td>
<td>Day 1</td>
<td>Day 2</td>
<td>Day 1</td>
<td>Day 2</td>
</tr>
<tr>
<td>Drop landing</td>
<td>19.1 ± 7.4°</td>
<td>19.6 ± 6.2°</td>
<td>12.2 ± 4.8°</td>
<td>12.9 ± 6.6°</td>
</tr>
<tr>
<td>ICC = 0.797, (p &lt; .001)</td>
<td></td>
<td></td>
<td>ICC = 0.886, (p &lt; .001)</td>
<td></td>
</tr>
<tr>
<td>(p = .73, \text{Cohen’s } d = 0.07)</td>
<td></td>
<td></td>
<td>(p = .47, \text{Cohen’s } d = 0.12)</td>
<td></td>
</tr>
<tr>
<td>SEM 1.2° (6.5%)</td>
<td></td>
<td></td>
<td>SEM 0.7° (5.8%)</td>
<td></td>
</tr>
<tr>
<td>Tuck back somersault</td>
<td>20.3 ± 7.4°</td>
<td>18.0 ± 8.0°</td>
<td>16.1 ± 6.9°</td>
<td>16.5 ± 5.5°</td>
</tr>
<tr>
<td>ICC = 0.750, (p &lt; .001)</td>
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<td></td>
<td>ICC = 0.840, (p &lt; .001)</td>
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<tr>
<td>(p = .22, \text{Cohen’s } d = 0.30)</td>
<td></td>
<td></td>
<td>(p = .75, \text{Cohen’s } d = 0.06)</td>
<td></td>
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<tr>
<td>SEM 1.9° (9.5%)</td>
<td></td>
<td></td>
<td>SEM 1.0° (6.1%)</td>
<td></td>
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<tr>
<td>Backaway</td>
<td>26.7 ± 9.6°</td>
<td>25.1 ± 7.0°</td>
<td>19.7 ± 9.0°</td>
<td>20.4 ± 9.4°</td>
</tr>
<tr>
<td>ICC = 0.500, (p &lt; .001)</td>
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<td></td>
<td>ICC = 0.619, (p &lt; .001)</td>
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<tr>
<td>(p = .53, \text{Cohen’s } d = 0.19)</td>
<td></td>
<td></td>
<td>(p = .06, \text{Cohen’s } d = 0.08)</td>
<td></td>
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<tr>
<td>SEM 3.5° (12.9%)</td>
<td></td>
<td></td>
<td>SEM 3.2° (12.7%)</td>
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</table>

*Comparison of frontal plane projection angle between tasks and between limbs. * Significantly \((p \leq .042)\) greater than drop landing; # significantly \((p \leq .038)\) greater than left leg. FPPA = frontal plane projection angle.
Discussion

This study aimed to determine within-session internal consistency and between-session reliability, and compare FPPA during different landing tasks in female gymnasts. Internal consistency of FPPA during each task showed moderate reliability, and high test-retest reliability for the drop landing and tuck back somersault, but only moderate test-retest reliability for the backaway. The most complex task, the backaway, showed the greatest FPPA, which was significantly greater than the FPPA observed during the drop landing task, in line with our hypothesis. In contrast to our hypothesis, a large and significant difference was observed between the right and left leg during the drop landing and backaway landing task.

No systematic learning effect was observed within each task, but the moderate session internal consistency for all the tasks demonstrates that lower limb control varies within session. Gymnasts perform numerous, repetitive landing tasks in training, and high variability of FPPA may be a potential risk factor in itself.

Assessment of FPPA during the drop landing task appears to be the most sensitive to changes in FPPA, with SEMs of 5.8–6.5% showing a meaningful change, and the tuck back somersault showing similar between-session reliability but slightly higher SEMs (6.1–9.5%). In contrast, the backaway only demonstrated moderate reliability and SEMs of 12.7–12.9%, showing a meaningful change; it is therefore suggested that the drop landing and tuck back somersault be used as appropriate tasks to screen FPPA in female gymnasts.

Gymnastic skills vary in terms of rotation of the body, flight, speed and ground reaction force, resulting in varied joint forces upon landing. Therefore, the assessment of FPPA during specific tasks may provide a more ecologically-valid assessment. The high FPPA and the moderate session internal consistency and test-retest reliability in the backaway landing task is likely due to the higher demands of the tasks in terms of both the complexity and higher forces involved. Gymnasts are exposed to a high frequency of high-impact landings, which, when combined with poor landing mechanics as observed from the high FPPA, may increase the risk of lower limb injury, although prospective studies are required to identify if this is the case. Results demonstrated high FPPAs across all tasks, when compared with previously reported drop landing FPPAs.

Future research should focus on different sport-specific tasks that occur in gymnastics that imitate the actions and movements of the sport. Researchers may investigate the element of twisting and rotation or they could focus on single leg landings such as leaps that are performed on the floor and beam exercise. Furthermore, future research should determine the effects of injury prevention programs on FPPA in gymnasts, with a view to identifying which intervention is most effective.

Conclusions

The FPPA of female gymnasts reported in this study demonstrates that female gymnasts may be at elevated risk of injury to the knee joint during landing tasks due to the increase knee valgus associated with a high FPPA. When assessing FPPA in female gymnasts, it is suggested that changes > 6.5% during the drop landing and > 9.5% during the tuckback somersault should be considered meaningful.

References
