The effect of overhead target on the lower limb biomechanics during a vertical drop jump test in elite female athletes

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The purpose of the study was to investigate the effect of an overhead target on the jump height and lower limb biomechanics in all three planes of motion in a vertical drop jump (VDJ) task among elite female handball and football (soccer) players. The hypothesis was that adding an overhead target to the VDJ task improves jump height, increases joint loading, and decreases frontal plane knee control. Five hundred and twenty-three female handball and football players (mean ± SD: 21 ± 4 years, 168 ± 6 cm, 65 ± 8 kg) completed the test. The overhead target increased jumping height by 5.8%. Furthermore, the overhead target led to statistically significant changes in many of the lower limb biomechanical variables examined. However, all the changes in kinematics and kinetics were clinically insignificant, as indicated by the small effect sizes. Strong to moderate positive Spearman’s rank correlations were found between the two conditions. Therefore, an overhead target is unlikely to increase the range of responses in biomechanical variables in elite female handball and football athletes.

Anterior cruciate ligament (ACL) injuries often occur in jump-landing situations (Boden et al., 2000; Krosshaug et al., 2007; Koga et al., 2010). The aim of the vertical drop jump (VDJ) test is to assess lower extremity neuromuscular control in a jump-landing situation (Hewett et al., 2005; Smith et al., 2012; Nilstad et al., 2014). Setting up the VDJ test is simple, whether in the field; using visual scoring, or in the laboratory; using more advanced motion analysis systems (Padua et al., 2009; Myer et al., 2011; Kristianslund & Krosshaug, 2013; Nilstad et al., 2014). In a small prospective study, Hewett et al. (2005) reported a significant association between frontal plane knee motion during a VDJ and the risk for ACL injuries. The VDJ test has therefore been advocated as a screening task in sports with a high risk of ACL injury (Padua et al., 2009; Myer et al., 2011; Smith et al., 2012), although the predictive ability of the test has yet to be replicated by others (Goetschius et al., 2012).

To mimic a jump-landing situation with match-like joint loading, several external stimuli have been tested. Verbal encouragement can enhance performance in exercise testing (Mcnair et al., 1996; Campenella et al., 2000). Introducing a target as an external focus could also improve exercise performance (Porter et al., 2010). Moreover, an external focus of attention could serve to distract the athlete and increase the automaticity in movement control (Wulf et al., 2001; Wulf & Dufek, 2007). Therefore, an overhead target can potentially increase joint loading and distract the athlete from focusing on frontal plane knee control when tested. An overhead target may therefore increase the range of response in biomechanical variables and thereby increase the sensitivity of the VDJ task to assess ACL injury risk.

Other than ACL injury risk, other common sports injuries, such as ankle instability (Delahunt et al., 2006) and patellofemoral pain (Boling et al., 2009), have been suggested to be associated with an inappropriate jump-landing technique. Moreover, the effect of an overhead target on jumping height and lower limb posture is of interest for therapist (Butler et al., 2003). Therefore, the current study reported the differences for a range of lower limb biomechanical variables.

Previous studies have confirmed that an overhead target increases jump height (Ford et al., 2005; Wulf & Dufek, 2007, 2009). Nonetheless, its effect on lower extremity biomechanics has not been investigated adequately. Wulf and Dufek (2009) concluded the overhead target increases lower extremity joint loading, but only in a limited sample of four male and six female university students. Ford et al. (2005) found significant increases in knee flexion angle and joint extensor moment in a sample of 18 collegiate athletes.
female athletes. However, the effect of an overhead target on frontal and transverse plane biomechanics has never been investigated. Moreover, the correlation of biomechanical measures between the two conditions is not known.

The objective of the current study was therefore to investigate the effect of an overhead target on jump height and lower limb biomechanics in all three planes of motion in a VDJ task in a sample of 523 elite female handball and football players. We hypothesized that adding an overhead target to the VDJ task would improve jump height, increase joint loading, and decrease frontal plane knee control.

Methods
Participants
The current study was part of a prospective cohort study aimed at investigating risk factors for noncontact ACL injuries in female elite handball and football players. Three hundred and sixty-three elite female football (soccer) and 160 elite female handball athletes (mean ± SD: 21 ± 4 years old, 168 ± 6 cm, 65 ± 8 kg) completed a VDJ task in target and non-target condition in our biomechanics laboratory between 2009 and 2014. The Regional Committee for Medical and Health Research Ethics South East approved the study and all athletes provided signed informed consent forms.

Data collection
The athletes wore indoor shoes, shorts, and a sports bra. The same, experienced physiotherapist attached 37 reflective markers over anatomical landmarks on the legs, arms, and torso (Kristianslund et al., 2012). All marker positions were uniquely defined, also those not defined by anatomical landmarks (Mok et al., 2015).

The athletes first performed the VDJ task in a non-target condition, and subsequently the VDJ task in a target condition. In the non-target condition, we instructed athletes to drop off a 30-cm stand and perform a maximal jump upon landing, with their feet on separate force platforms (AMTI LG6-4-1; Watertown, Massachusetts, USA). They were allowed to have three practice trials and data from at least three valid trials were collected for each athlete. At least two test operators observed the execution of the jump and monitored 30–45 s rest between trials. If a submaximal effort was suspected, or when jumping instead of dropping off the stand (i.e., increasing the vertical center of mass position at take-off from the stand), we asked the athlete to repeat the jump. Athletes received verbal encouragement to give a maximal jump effort.

In the target condition, we set up a horizontal bar as an overhead target, about 30 cm in front of the athlete (Fig. 1). The height of the bar was set based on jump height in the VDJ task in the non-target condition. We asked the athletes to perform a VDJ and reach the bar by the head. If the athlete managed to reach the bar, it was raised in increments of five cm or less. The task ended when the athlete failed to reach the same height twice and at least three valid trials had been collected. The final three valid trials of each athlete were used for the analysis.

We used a 480 Hz 16-camera system (Oqus 4; Qualisys, Gothenburg, Sweden) to capture motion, while we recorded ground reaction forces using two force platforms collecting at 960 Hz (AMTI LG6-4-1; Watertown). We calibrated the motion analysis system according to guidelines from the manufacturer, and calculated and tracked marker trajectories using the Qualisys Track Manager (Qualisys).

Data processing
We defined the contact phase as the period where the unfiltered vertical ground reaction force exceeded 20 N. Marker trajectories and force data were filtered and interpolated using Woltring’s smoothing spline in the cubic mode (Woltring, 1986), using a 15 Hz cut-off (Kristianslund et al., 2012). We calculated the hip joint center using the method proposed by Bell et al. (1990), with the anterior–posterior position of the hip joint decided by the anterior–posterior position of the marker over the greater trochanter. Furthermore, we defined the knee joint center according to Davis et al. (1991), and the ankle joint center according to Eng and Winter (1995). Anatomical coordinate systems of each segment were determined from the static calibration trials. We defined the vertical axis in the direction from the distal to the proximal joint center, while the anterior-posterior axis was defined perpendicular to the vertical axis with no mediolateral component. The third axis was the cross product of the vertical and antero-posterior axes. Consequently, all segments had neutral internal/external rotation in the static calibration trial. We obtained technical and dynamic segment coordinate systems using an optimization procedure involving singular value decomposition (Soderkvist & Wedin, 1993).

We estimated inertia parameters based on 46 measures of segment heights, perimeters, and widths using a modified
Yeadon’s method (Yeadon, 1990), hand and foot parameters calculated with the method of Zatsiorsky and Seluyanov (1983). We calculated joint moments with inverse dynamics using recursive Newton–Euler equations of motion as described by Davis et al. (1991) and projected onto the three rotational axes of the joint according to the joint coordinate system standard (Grood & Suntay, 1983; Kristianslund et al., 2014).

We used the Grood and Suntay (1983) convention for calculating joint angles from the marker-based motion analysis. We calculated medial knee position as the perpendicular distance between the knee joint center and the line joining the ankle and hip joint centers, projected on the frontal plane. The difference between the medial knee position at the initial foot contact and the peak value was defined as the medial knee displacement. An advantage of this convention compared with a pure knee separation measure is that we can assess knee control individually for the left and right leg. We compared with a pure knee separation measure is that we can assess knee control individually for the left and right leg. We ran all calculations using custom Matlab scripts (MathWorks Inc., Natick, Massachusetts, USA).

### Statistical analysis

Jump height was defined by the difference of the vertical center of mass position between the static anatomical position and the maximal height position during the jump. Thirty selected biomechanical variables were extracted from the joint kinematics, joint kinetics, and force time course for the analyses. We extracted variables for both legs and organized them into dominant and non-dominant side. The mean of three trials for each athlete was used for the analysis of each variable. A two-way ANOVA was used to determine the main effects and interaction of side dominance and condition on each variable. If a significant interaction was found, post-hoc paired t-tests were done separately for the dominant and non-dominant side. We report the mean with standard deviation for each variable from the two conditions. Moreover, we computed effect size as the mean difference divided by the pooled standard deviation to assess the clinical significance of the mean difference between conditions (Cohen, 1992). We interpreted effect size as follows: <0.2, no effect; 0.2–0.5, small effect; 0.5–0.8, medium effect; >0.8, large effect (Cohen, 1992).

To assess the consistency of athlete ranking between two conditions, we calculated Spearman’s rank correlation coefficients based on the measurements from the non-target and target condition and the rank correlation coefficients >0.8 as strongly positive and 0.5–0.8 as moderately positive (Zou et al., 2003). Statistical significance was set at $P < 0.05$. Statistical analyses were performed using SPSS 18 (SPSS Inc., Chicago, Illinois, USA).

### Results

Jump height increased by 5.8% when athletes reached for an overhead target, corresponding to a medium effect size (Table 1). Of all variables studied (Table 1), a significant interaction between side dominance and task was only observed for medial knee displacement ($P = 0.02$). We therefore analyzed the dominant and non-dominant side results separately for this variable, whereas data for the dominant and non-dominant side were combined for the remaining variables. The addition of an overhead target resulted in a significant change in the majority of the biomechanical variables examined; however, the effect sizes were small (Table 1). We observed a strong rank correlation between the two tasks in 23 out of the 32 variables, and a moderate correlation in the remaining nine (Table 1). The medial knee displacement variable had the lowest rank correlation.

### Discussion

The main finding of this study was that introducing an overhead target increased jump performance by 5.8% and led to statistically significant changes in many lower limb biomechanical variables. Our results are generally consistent with previous studies, including the increase in jump height and joint loading when introducing an overhead target (Ford et al., 2005; Wulf & Dufek, 2009). However, the changes in kinematics and kinetics are likely to be clinically insignificant, as indicated by the small effect sizes. The explanation for this apparent discrepancy is the unprecedented sample size of 523 players.

Comparing the two conditions, we recorded a 5.0% increase in peak vertical ground reaction force (Table 1), which corresponds well to the increase in jump height. This demonstrates that an external motivation enhanced the effort even if we provided strong verbal encouragement for the non-target task and also asked the athletes to repeat the trial if a sub-maximal effort was suspected.

The overhead target generated a stiffer landing, which may in turn increase the load on the ACL. We recorded a 4.4° decrease in peak knee flexion angle, a 7.0° decrease in the range of knee flexion and a 65 N increase in peak vertical ground reaction force (Table 1). The results are consistent with previous studies assessing differences between soft and stiff landings (Devita & Skelly, 1992; Pollard et al., 2010; Myers et al., 2011). It is known that higher vertical ground reaction force and extended knee position in stiff landings will increase ACL strain due to the increased anterior tibial translation (Markolf et al., 1995; Myers et al., 2011). In contrast, soft landings will allow the vertical ground reaction force to be dissipated over a larger range of knee flexion than stiff landings (Devita & Skelly, 1992; Pollard et al., 2010; Myers et al., 2011), and are therefore advocated as a preventive strategy for reducing ACL injuries in successful injury prevention programs (Boden et al., 2000; Myer et al., 2004; Mandelbaum et al., 2005; Myklebust et al., 2013; Taylor et al., 2015). However, again the effect sizes were small, suggesting that these differences are unlikely to be clinically relevant.

The rank correlations observed for the various measures of lower limb biomechanics between the two conditions are generally interpreted as strong to moderate. Even so, when applying these tasks as
Table 1. Comparison of biomechanical variables during vertical drop jumps in target and non-target conditions (n = 523). Data are shown as means, standard deviations (SD), mean differences (percent change in parentheses) with 95% confidence interval (CI), effect sizes (Cohen’s d), and Spearman’s rank correlation coefficients. Positive values denote an increased score with the addition of an overhead target; statistically significant differences are shown in bold.

<table>
<thead>
<tr>
<th>Comparison</th>
<th>Non-target condition</th>
<th>Target condition</th>
<th>Mean difference (95% CI)</th>
<th>Effect size</th>
<th>Spearman’s rank correlation coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jump height (cm)</td>
<td>41.6 ± 4.8</td>
<td>44.0 ± 5.0</td>
<td>2.4 (2.2–2.7)</td>
<td>0.51</td>
<td>0.84</td>
</tr>
<tr>
<td>Kinematics</td>
<td></td>
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</tr>
<tr>
<td>Hip flexion angle at IC (°)</td>
<td>48.3 ± 8.5</td>
<td>49.9 ± 8.4</td>
<td>1.6 (1.3–2.0)</td>
<td>0.20</td>
<td>0.79</td>
</tr>
<tr>
<td>Peak hip flexion angle (°)</td>
<td>83.0 ± 15.6</td>
<td>78.2 ± 15.5</td>
<td>–4.8 (–5.4 to –4.4)</td>
<td>0.31</td>
<td>0.85</td>
</tr>
<tr>
<td>Hip abduction angle at IC (°)</td>
<td>5.3 ± 3.6</td>
<td>5.0 ± 3.8</td>
<td>–0.3 (–0.4 to –0.1)</td>
<td>0.07</td>
<td>0.86</td>
</tr>
<tr>
<td>Peak hip abduction angle (°)</td>
<td>7.6 ± 3.9</td>
<td>7.2 ± 3.9</td>
<td>–0.4 (–0.6 to –0.4)</td>
<td>0.12</td>
<td>0.86</td>
</tr>
<tr>
<td>Hip internal rotation angle at IC (°)</td>
<td>–0.6 ± 5.3</td>
<td>–0.5 ± 5.4</td>
<td>0.1 (–0.1 to 0.2)</td>
<td>0.01</td>
<td>0.90</td>
</tr>
<tr>
<td>Peak hip internal rotation angle (°)</td>
<td>4.6 ± 5.6</td>
<td>4.4 ± 5.6</td>
<td>–0.2 (–0.3 to 0.0)</td>
<td>0.03</td>
<td>0.90</td>
</tr>
<tr>
<td>Knee flexion angle at IC (°)</td>
<td>32.3 ± 7.9</td>
<td>34.9 ± 8.1</td>
<td>2.6 (2.3–2.9)</td>
<td>0.33</td>
<td>0.81</td>
</tr>
<tr>
<td>Peak knee flexion angle (°)</td>
<td>93.5 ± 14.8</td>
<td>89.1 ± 13.5</td>
<td>–4.4 (–5.0 to –3.9)</td>
<td>0.31</td>
<td>0.80</td>
</tr>
<tr>
<td>Range of knee flexion (°)</td>
<td>61.2 ± 16.8</td>
<td>54.2 ± 15.5</td>
<td>–7.0 (–8.4 to –5.6)</td>
<td>0.43</td>
<td>0.79</td>
</tr>
<tr>
<td>Knee valgus angle at IC (°)</td>
<td>–2.0 ± 4.2</td>
<td>–1.8 ± 4.4</td>
<td>0.2 (0.18–0.4)</td>
<td>0.07</td>
<td>0.92</td>
</tr>
<tr>
<td>Peak knee valgus angle (°)</td>
<td>5.1 ± 5.2</td>
<td>5.6 ± 5.2</td>
<td>0.5 (0.4–0.6)</td>
<td>0.10</td>
<td>0.95</td>
</tr>
<tr>
<td>Knee internal rotation angle at IC (°)</td>
<td>–0.5 ± 5.4</td>
<td>0.3 ± 5.7</td>
<td>0.8 (0.6–1.0)</td>
<td>0.15</td>
<td>0.83</td>
</tr>
<tr>
<td>Peak knee internal rotation angle (°)</td>
<td>10.4 ± 6.1</td>
<td>9.9 ± 5.9</td>
<td>–0.5 (–0.6 to –0.3)</td>
<td>0.07</td>
<td>0.94</td>
</tr>
<tr>
<td>Ankle plantarflexion at IC (°)</td>
<td>10.9 ± 9.7</td>
<td>11.3 ± 9.1</td>
<td>0.4 (0.1–0.8)</td>
<td>0.04</td>
<td>0.77</td>
</tr>
<tr>
<td>Peak ankle plantarflexion angle (°)</td>
<td>25.1 ± 7.3</td>
<td>25.1 ± 7.1</td>
<td>0.02 (–0.2 to 0.2)</td>
<td>&lt;0.01</td>
<td>0.89</td>
</tr>
<tr>
<td>Ankle inversion angle at IC (°)</td>
<td>9.3 ± 5.2</td>
<td>8.5 ± 5.2</td>
<td>–0.8 (–1.0 to –0.6)</td>
<td>0.16</td>
<td>0.83</td>
</tr>
<tr>
<td>Peak ankle inversion angle (°)</td>
<td>10.8 ± 4.6</td>
<td>10.2 ± 4.7</td>
<td>–0.6 (–0.7 to –0.4)</td>
<td>0.11</td>
<td>0.85</td>
</tr>
<tr>
<td>Ankle internal rotation angle at IC (°)</td>
<td>0.5 ± 6.6</td>
<td>–0.1 ± 6.7</td>
<td>–0.6 (–0.7 to –0.5)</td>
<td>0.09</td>
<td>0.87</td>
</tr>
<tr>
<td>Peak ankle internal rotation angle (°)</td>
<td>6.1 ± 6.1</td>
<td>5.6 ± 6.2</td>
<td>0.5 (–0.6 to 0.3)</td>
<td>0.08</td>
<td>0.80</td>
</tr>
<tr>
<td>Medial knee displacement on the dominant side (cm)*</td>
<td>2.2 ± 1.3</td>
<td>2.4 ± 1.6</td>
<td>0.2 (0.1–0.3)</td>
<td>0.15</td>
<td>0.58</td>
</tr>
<tr>
<td>Medial knee displacement on the non-dominant side (cm)*</td>
<td>2.1 ± 1.4</td>
<td>2.0 ± 1.6</td>
<td>–0.08 (–0.1 to 0.0)</td>
<td>0.06</td>
<td>0.63</td>
</tr>
</tbody>
</table>

*Kinetics

| Peak vertical GRF (N) | 1294.6 ± 391.6 | 1359.5 ± 400.7 | 64.9 (48.9–80.7) | 0.16 | 0.77 |
| Peak hip flexion moment (Nm) | 203.3 ± 46.3 | 208.2 ± 52.4 | 4.9 (2.9–6.8) | 0.10 | 0.80 |
| Peak hip abduction moment (Nm) | 40.0 ± 17.1 | 41.4 ± 17.8 | 1.4 (0.8–2.1) | 0.08 | 0.77 |
| Peak hip internal rotation moment (Nm) | 20.1 ± 9.5 | 20.8 ± 10.1 | 0.7 (0.3–1.0) | 0.07 | 0.81 |
| Peak knee flexion moment (Nm) | 141.3 ± 37.3 | 150.1 ± 40.3 | 8.8 (7.5–10.1) | 0.23 | 0.87 |
| Peak knee abduction moment (Nm) | 20.5 ± 10.7 | 21.7 ± 12.1 | 1.2 (0.7–1.6) | 0.10 | 0.78 |
| Peak knee internal rotation moment (Nm) | 10.2 ± 6.9 | 11.1 ± 7.7 | 0.9 (0.6–1.1) | 0.12 | 0.83 |
| Peak ankle dorsiflexion moment (Nm) | 112.7 ± 31.0 | 120.4 ± 4.8 | 7.7 (6.5–8.8) | 0.23 | 0.85 |
| Peak ankle inversion moment (Nm) | 1.8 ± 4.0 | 2.0 ± 4.6 | 0.2 (0.0–0.3) | 0.04 | 0.78 |
| Peak ankle internal rotation moment (Nm) | 16.5 ± 8.7 | 17.5 ± 9.7 | 1.0 (0.7–1.3) | 0.11 | 0.85 |

There are some limitations that should be borne in mind when interpreting the results of the current study. Marker placement and soft tissue artifacts are well-known sources of error in a skin marker-based motion analysis (Leardini et al., 2005; Miranda et al., 2013). However, since marker placement was standardized, these errors are expected to be similar for the two tasks and unlikely to have affected our findings. The fact that we did not randomize the task order means that fatigue may have been induced in the target condition, which was always performed last. However, considering that they were able to jump 2.4 cm higher in the target condition, fatigue effects were likely small. Another potential limitation is that reaching a horizontal bar by the head may pose less of a challenge for neuromuscular control.
than, e.g., grasping an overhead ball. Lastly, it is still unknown how the other demographic factors, such as gender and age, could have affected the results. Therefore, the generalizability of these results to players of a different skill level, sport or even injury history is unknown.

**Perspectives**

Adding an overhead target to the VDJ test improves jump height, but generates only minor changes in lower limb biomechanics. In addition, athlete ranking based on the lower limb biomechanics was consistent between the two conditions. Therefore, an overhead target does not increase the range of responses in biomechanical variables among elite female handball and football athletes. Nevertheless, an investigation involving prospective injury data collection is necessary to determine if including an overhead target increases the sensitivity and specificity of the VDJ test for identifying players with high risk for a future ACL injury.

**Key words:** ACL injury, knee, risk screening task, 3D motion analysis, joint loadings.

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