INTRODUCTION
Patellofemoral pain syndrome (PFPS) accounts for about 25% of knee injuries in athletes [1]. Backward running (BR) is used as a rehabilitation method for PFPS patients, as it appears less painful than forward running (FR). BR has been reported to have reduced patellofemoral joint compression forces (PFJCF) compared to FR [2], speeds in the BR trials were however lower than in the FR trials. These reduced PFJCFs may therefore be due to the slower speed and not to running style. Another study found no difference in PFJCF when running forward and backward at the same speed [3]. The running speeds in this study were however unnaturally slow. The aims of this study were therefore to investigate 1) if BR has a reduced peak PFJCF compared to FR at the same speed, and 2) if this force is reduced in BR, to investigate whether this is due to a change in kinematics or a change in kinetics.

METHODS
Eleven healthy volunteers (4 male, 7 female, age: 27±7 years, height: 1.74±0.04 m, mass: 68.3±10.5 kg) were asked to run along a 7-meter runway in a forward (FR) and backward (BR) direction at a speed between 2.8 and 3.4 m/s. Ethical approval was obtained from the Human Research Ethics Committee of the School of Healthcare Studies at Cardiff University. For each subject three trials of both conditions were collected. Kinematic data were collected using an eight camera VICON motion analysis system (Oxford Metrics Group Ltd., UK) at 200 Hz. Reflective markers were placed using the lower limb ‘Plug-in-Gait’ markerset. Ground reaction force data were collected using two Kistler forceplates (Kistler Instruments Ltd., Switzerland) at 1000 Hz. Data analysis selected right foot contact with the forceplate. Inverse dynamics calculations were performed within VICON Nexus software, and data were subsequently processed and analysed within Matlab R2010b (The Mathworks Inc., USA).

The PFJCF was calculated in Matlab, combining kinematic and kinetic data from VICON Nexus with values for the patella tendon moment arm (dPT) and the patella mechanism angle from literature [4]. The dTP was scaled to knee angle and subject height. PFJCF was calculated as follows:

\[
PFJCF = \frac{R_{Fq-Fp}}{F_q} \quad \text{(Equation 1)}
\]

with \(Q_{Tforce}(F_q) = \frac{M_k}{dPT} \quad \text{(Equation 2)}\)

where \(R_{Fq-Fp}\) is the ratio between the quadriceps and patella tendon force, \(F_q\) is the patella tendon force, \(Q_{Tforce}\) is the quadriceps tendon force and \(M_k\) is the knee moment. \(R_{Fq-Fp}\) was extrapolated from [5]. PFJCF was normalised relative to body weight.

To investigate the kinematics and kinetics of BR and FR a telescopic inverted pendulum (TIP) model approach was used (Figure 1). Walking can be simulated by a simple inverted pendulum model, where the stance limb is modeled as a rigid segment that rotates around the ankle [6]. FR has a large compression and passive recoil of the stance limb (telescopic motion) and can therefore better be modeled by a spring mass model [7]. The TIP model approach will show whether BR has a predominantly telescopic motion like FR (large change in stance leg length (Ls)), or predominantly pendular motion (large change of the approach angle of the contact leg (\(\theta_k\)).

Statistical differences for the output variables between FR and BR were calculated with an independent t-test.

RESULTS AND DISCUSSION
Running speed was not significantly different between FR and BR (3.0±0.1 and 3.1±0.2 m/s respectively, p>0.001, Table 1). PFJCF was significantly higher in FR than in BR (4.7±1.6 and 3.7±1.7 BW respectively, p<0.05, Table 1). This shows that the PFJCF was reduced in BR compared to FR when running at the same speed. The peak knee extensor moment was significantly higher in FR than in BR (159±59 and 128±59 Nm respectively, p<0.05, Table 1), while the knee angle (\(\theta_k\)) at this peak knee moment was not significantly different between FR and BR (p>0.05, Table 1). This indicates that the kinetics (higher knee extensor moments) and not the knee angle caused the reduced PFJCF in BR.

Figure 1: Schematic overview TIP model for FR on the left and BR on the right, with the approach angle (\(\theta_s\)), knee angle (\(\theta_k\)), and length (L) of the contact leg.
TIP model calculations (Figure 2) showed that the peak knee extensor moment occurred at a smaller approach angle of the contact leg ($\theta_c$) in FR than in BR (79±3° and 84±5° respectively, p<0.05, Table 1). In BR the body was therefore more upright at the time of the peak knee extensor moment than in FR. Both values for $\theta_c$ at the peak knee moment were smaller than 90°. The body was therefore leaning forward at the time of the peak knee moment in both FR and BR. The peak knee moment therefore generated a loading response and push-off in FR, and a loading response but no push-off in BR.

![Figure 2: Output of TIP model calculations with stance leg length (L) against approach angle of the contact leg (θ). The grey solid lines are the average data for backward running and the black solid lines are the average data for forward running, with the thinner solid lines for the push-off phase. The dashed lines are the ±1 standard deviation lines. The stars indicate where the peak knee extensor moments occurred, and the arrows point in the direction of movement. FRPO and BRPO are the push-off in FR and BR respectively.](image)

In both FR and BR the stance leg shortens during the initial deceleration phase, and extends during the push-off phase (Figure 2). In FR the stance leg extended more during the push-off phase than in BR (Figure 2), and the body was leaning forward during this push-off phase ($\theta_c$>90°), resulting in loading response as well as push-off. This is typical behavior that can be modeled by a spring mass model (such as [6]). In BR the general orientation of the body was more upright than in FR. This was most likely due to the anatomy of the ankle and knee joints, and in order to maintain balance. As the peak knee extensor moment in BR did not provide push-off ($\theta_c$<90°), we propose BR can better be generated by pendular movement. Pendular movement would not require high knee extensor moments, but high hip flexor moments in order to generate push-off. This was confirmed by the significantly higher peak hip flexor moments in BR compared to FR (120±39 and 54±24 Nm respectively, p<0.05, Table 1). Interestingly, for some of the participants (four in total) PFJCFs were similar in BR and FR. This may be due to the difference in heel and forefoot strike of the runners used when running forward. Due to the small sample size, no significant differences could be found between the participants with and without a decreased PFJCF. This requires further investigation into whether BR is beneficial for PFPS patients, or whether an adapted FR style would be just as beneficial.

**CONCLUSIONS**

Patellofemoral joint compression force (PFJCF) was lower in backward (BR) than in forward running (FR) and this difference was not due to a difference in speed. The knee angles at the peak knee extensor moment were similar in BR and FR, kinetics were however different with higher peak knee extensor moments in FR and higher peak hip flexor moments in BR. This increased peak knee extensor moment was therefore related to the increased PFJCF in FR. These differences were not consistent in all participants, therefore further research is required to investigate whether it is the BR style that resulted in a reduced PFJCF or whether an adapted FR style could also be advised to reduce knee pain in patellofemoral pain syndrome patients.

**REFERENCES**


<table>
<thead>
<tr>
<th></th>
<th>Speed (m/s)</th>
<th>PFJCF (BW)</th>
<th>Peak knee extensor moment (Nm)</th>
<th>$\Theta_K$ at peak knee moment (°)</th>
<th>$\Theta_L$ at peak knee moment (°)</th>
<th>Peak hip flexor moment (Nm)</th>
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<tbody>
<tr>
<td><strong>Forward</strong></td>
<td>3.0 ± 0.1</td>
<td>4.7 ± 1.6</td>
<td>159 ± 59</td>
<td>41 ± 5</td>
<td>79 ± 3</td>
<td>54 ± 24</td>
</tr>
<tr>
<td><strong>Backward</strong></td>
<td>3.1 ± 0.2</td>
<td>3.7 ± 1.7*</td>
<td>128 ± 59*</td>
<td>42 ± 5</td>
<td>84 ± 5*</td>
<td>120 ± 39*</td>
</tr>
</tbody>
</table>

Table 1: Mean running speed, patella femoral joint compressive force (PFJCF), peak knee moment, knee angle at peak knee moment, and leg angle ($\theta$) at peak knee moment, with standard deviations for forward and backward running. A * indicates that the backward running condition was significantly different from forward running with p < 0.05.