INTRODUCTION

With the increase in the use of artificial turf in sports, there is a need to measure the human/surface interactions accurately in order to identify possible mechanisms that could lead to injury. Previous assessments of artificial turfs utilised mechanical rigs that apply loads to the surface that are not biomechanically relevant (Nigg, 1990). Subject testing of artificial turf usually employs a force plate to measure the loadings applied by the subject during dynamic movements. The turf is attached to the top surface of the force plate, which measures the loads transmitted from the subject through the artificial turf. Under high dynamic loading the artificial surface may exhibit an inertial effect, which could significantly affect the measurement of the applied load by the force plate:

\[
F_{fp} = F_{ap} - m_{at}a
\]  

(1)

\(F_{fp}\) = force measured by the force plate
\(F_{ap}\) = force applied
\(m_{at}\) = inertial force of the turf

There has not been any previous research that has examined this possibility. The aim of this project is to assess the accuracy of using a forceplate to measure the dynamic loading actions at the human/surface interface on artificial turfs.

METHODS

A test rig (Figure 1) was used to measure the vertical force produced from dynamic loads (Praagman, 1997). The rig was constructed to transmit vertical loads to a single-axis Kistler 9321B force transducer (‘Force-link’) placed on top of the artificial turf, which was attached to a force plate (Kistler 9281B). The rig was designed to minimise any friction and prevent the transmission of any horizontal loads. The aluminium plates were hinged to a vertical steel support plate, which was bolted to the floor surrounding the force plate to provide stability. Three artificial turfs were tested: Turf 1 (short pile, sand infill); Turf 2 (medium pile, sand infill); Turf 3 (FieldTurf® long pile, sand/rubber infill). Turf 1 and 2 used a 10mm rubber underlay. The turfs were installed over the force plate according to manufacturers’ guidelines. A subject applied a range of loads by jumping from different heights (35cm and 50cm). Two sizes of circular test foot were used: one to represent foot-flat (F1) contact area (160mm²) and the other fore-foot (F2) contact area (110mm²). These areas were based on a standard UK size 10 shoe. The test rig placed directly on the force plate, using the foot-flat (F1) test foot was used as a control condition.

The errors were calculated as the difference between the peak forces recorded by the force plate to those recorded from the force link, relative to the peak force link output. Secondly, the mean of the difference between the two outputs over the first 100 samples from initial contact was calculated to provide an indication of the error during the whole impact phase of the jumps performed. The force-link measured slightly higher peak values than the force-plate, although the relative errors were below 0.6% (Figure 2). The difference between the highest observed error (Turf 3, F1) and the control was approximately 0.3%. The greatest absolute peak error was 29N at a peak force of 5780N on Turf 2 (F2). The smallest absolute peak error was 0.05N at a peak force of 548N on Turf 1 (F1). The difference in error...
between the two sizes of contact areas on all three turfs was small (less than 0.15%).

Turf 3 with the F2 test foot produced the highest mean error of 10 (±6.8) N during the impact phase of the jump. The inertial force calculated from the acceleration of the test foots F1 and F2 on turf 2 were below 1N for all trials and are therefore insignificant.

**Figure 2:** Mean relative error between peak force plate and force-link outputs

<table>
<thead>
<tr>
<th>Test</th>
<th>Applied Load Range (N)</th>
<th>Peak Error Range (N)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control (n=8)</td>
<td>936-3136</td>
<td>1.79-11.8</td>
</tr>
<tr>
<td>Turf 1 (F1) (n=11)</td>
<td>548-4188</td>
<td>0.05-11.7</td>
</tr>
<tr>
<td>Turf 1 (F2) (n=11)</td>
<td>633-4310</td>
<td>2.2-11.0</td>
</tr>
<tr>
<td>Turf 2 (F1) (n=11)</td>
<td>644-5784</td>
<td>0.95-29.4</td>
</tr>
<tr>
<td>Turf 2 (F2) (n=11)</td>
<td>678-4076</td>
<td>2.02-12.1</td>
</tr>
<tr>
<td>Turf 3 (F1) (n=8)</td>
<td>602-4439</td>
<td>1.0-28.1</td>
</tr>
<tr>
<td>Turf 3 (F2) (n=8)</td>
<td>668-3027</td>
<td>0.3-16.2</td>
</tr>
</tbody>
</table>

**Table 1:** Ranges of dynamic applied loads

**Figure 3:** Mean absolute errors (taken over 100 samples from first impact) between force plate and force-link outputs

**DISCUSSION**

This errors calculated in this study could arise from a combination of the inertial effects of the artificial surface and the test foot, and the accuracy of the measuring systems. Nigg (1990) reported that the inertial effect of artificial turf was approximately 4N, although no data was presented. This study produced higher absolute values at peak forces, although it was considered insignificant when calculated relative to the magnitude of the applied peak force. It was observed that the higher the applied peak forces the higher the error between the two outputs. Analysis of the data over the whole impact phase (100 samples/93msec from the initial impact) showed that the mean error magnitude was below 10N. The FieldTurf (turf 3) artificial turf was the ‘softest’ of the three turfs to be tested and exhibited the greatest inertial effects. A ‘softer’ turf will displace more under load, absorbing some of the energy of the impact. Therefore, a greater effective mass of turf will be displaced and have a greater inertial force.

The radius and mass of the test foot has been shown to affect the deformation of the surface during an impact (Nigg & Yeadon, 1987). A relatively large area of artificial surface deforming under loading may exhibit a significant inertial force. During this study however, increasing the size of contact area did not significantly affect the error between the two outputs. In addition, it was observed that the inertial effect of the test foots was minimal.

The accuracy of this type of force plate and force-link was specified to be ±0.5% and ±0.2%, respectively. A combined, total error of the whole measuring system is 0.7%. The relative errors measured in this study fall within or very slightly over these limits and can therefore be regarded as insignificant.

The range of forces applied in this study was large, in an attempt to cover the diversity of applied forces observed in sporting activities. However, this study did not include the assessment of shear forces that are applied during sporting activities. These shear forces are usually lower than the vertical forces observed. It could be inferred from the results of this study that the possible inertial effect of the artificial in the horizontal direction would also be minimal.

The errors observed in this study are insignificant. It can be concluded that any inertial effect of artificial turf during the biomechanical assessment of sporting movements on such surfaces is minimal and validates the use of force plates to measure the loading actions at the human/surface interface.

**REFERENCES**