INTRODUCTION

The increasing number of people playing outdoors sports such as football, has resulted in more frequent use of artificial playing surfaces which have been designed for wider access, for its versatility, for economic and climatic reasons, and to speed up the game.

The governing body of European football (UEFA), after extensive tests, has recently published guidelines and standards that would enable official competitions to be played on artificial turf from the 2004/2005 season onwards. However, with the development and introduction of artificial turfs, concerns over the severity and frequency of sports injuries and have been raised, leading turf manufacturers to re-design their turf.

Even though the National Football League and the National Collegiate Athletic Association were the first to install artificial turf for official games, in the fall of 1966 for the NFL Houston Oilers at the Astrodome, and at the Indiana State University Stadium in 1967, 1999 marked the first time since the early ‘70s that grass fields outnumbered synthetic fields in the NCAA’S division 1-A, and in 2000 70 out of 109 division 1-A schools used natural grass as their playing surface, while 11 NFL teams out of 32 plays on artificial turf. The change towards synthetic fields almost two decades ago centered on two key arguments: the surface would save campuses large sums of money in field maintenance, and would allow athletes to make cleaner and faster “cuts”, despite the concern from athletes, trainers of an increase in “foot-fixation” injuries.

A large numbers of studies have been dedicated to injuries on sports surfaces with mixed results. Some reports show that there are more injuries on artificial turf than on natural grass, (Powell et al. (1992), Zemper, D. (1998)), while some others, (Renstrom et al 1997), Nicholas et al (1998)) found no significant differences in the number of injuries between games played on artificial turf and natural grass. Both sides agree that due to the constant change in game strategies and rules as well as players’ size, movement, intensity, equipment, conditioning, and medical care, the game have changed radically leading to an improved level with a faster pace over the last three decades, provoking a larger number of injuries, and a significant number of new types of injuries which were rare on natural turf. A 1996 survey conducted by the National Football League Players’ Association found 82.3 percent of players dislike playing on artificial turf. When it comes to injuries, 93.4 percent felt artificial turf is more likely to contribute to injury.

Therefore in order to meet the demands and requirements of players, and to prevent injuries, tests have been carried out to show the importance of the integration of the biomechanical properties of the players on turfs to fully understand the interaction between players and sports surfaces.

Characterisation of the accelerations experienced by the athletes during sporting activities will provide an indication of the severity of these activities and the possibility of related injury. Recordings of the accelerations of the pelvis and shank during simulated sporting activities have been made to allow comparison of techniques adopted on natural and artificial turf under a range of conditions.

METHODS

The players (pro and semi-pro level) recruited for this study: 5 footballers (all male, ages 26-42), 4 hockey players (2 male, 2 female, ages 19-24), 4 rugby men (ages 22-27) were instrumented with two single axis piezo-resistive accelerometers (Entran EGCS-D1SM-50, +/- 50g range, 0-600Hz frequency response), one on the pelvis, one on the left shank, measuring the impact accelerations of the shank and the pelvis during heel strike), and a flexible electrogoniometer (Biometrics XM180), on the left knee, lateral aspect, aligned with the long axis, measuring the knee angle of the non-dominant leg during heel strike.

A portable digital data logger (Biomedical Monitoring, BM42) sampled the outputs of the accelerometers and goniometer at 500 Hz sampling frequency, in order to provide a quantifiable link between the laboratory testing and field-testing. An electric pulse was used to light a LED enabling the synchronization between the video and the accelerations during heel strike (square wave in the data logger output) was plugged into the fourth channel of the data logger.

One of the accelerometers was attached to an aluminium plate midway between the posterior superior iliac spines (MPSIS). The aluminium plate was secured in place by an elastic belt around the pelvis. The other accelerometer was affixed to a small piece of balsa wood and attached to the medial, distal aspect of the athlete’s non-dominant leg, 20% of the distance from the medial malleolus to the tibial tuberosity. It was secured in place by 3M Vetrap.

The flexible electrogoniometer was attached to the lateral aspect of the athlete’s knee on the non-dominant leg with toupee tape. The electrogoniometer and the connecting cables of the shank accelerometer were secured in place with an elastic tubular bandage.

The 4-channel data logger was clipped to the pelvis belt worn by the athlete on the front side. The two accelerometers, the goniometer and the event marker system were plugged into the 4 channels of the data logger.
A digital video camera (25Hz, 1/120 s shutter speed) was used during indoor and outdoor testing to provide a visual reference of the sports movements performed by the athletes, and to compare the style of the athletes’ outdoors (artificial turf and natural grass) and indoors (artificial turf).

The athletes were unrestrained and were able to perform the sports activities like they would during a game. Each movement was repeated three times at maximum effort in order to get reproducible, reliable and consistent data.

The footballer, wearing preferred shoes to perform a natural execution of the movements, was asked to perform specific sport activity movements, such as a run and a 45-degree turn to the right, at maximal effort, on seven different turfs: three indoor turfs (short pile Astroturf sand infill with rubber underlay, Fieldturf long pile turf with sand/rubber infill, medium pile turf half filled with sand) and four outdoor turfs (long and short natural grass, Fieldturf under dry and wet conditions, medium pile turf under dry and wet conditions).

The wet condition was simulated by sprinkling 20 litres of water over the area, Figure 1, (around 50 m²) where the footballer was performing the sports movement.

![Figure 1: Plan of the test area (indoor, outdoor)](image)

(Green: 90-degree left, Red: 45-degree right, Black: run, “run-stop”, specific sports movements)

### RESULTS AND DISCUSSION

The Tables 1a, 1b, 1c summarize the maximum pelvis and shank filtered accelerations of the footballer during heel strike performing a 45-degree turn to the right with the left leg on the seven different turfs: natural long and short fully drained grass, both being naturally wet, a new Astroturf short pile sand infill (with rubber underlay), new Fieldturf indoor, worn Fieldturf outdoor under wet and dry conditions, a new indoor medium pile turf, and worn medium pile turf under dry and wet conditions.

<table>
<thead>
<tr>
<th>Turf</th>
<th>Natural long grass</th>
<th>Natural short grass</th>
<th>New Fieldturf indoor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum shank acceleration (g)</td>
<td>32.91</td>
<td>35.3</td>
<td>32.87</td>
</tr>
<tr>
<td>Maximum Pelvis acceleration (g)</td>
<td>3.93</td>
<td>5.07</td>
<td>3.77</td>
</tr>
</tbody>
</table>

**Table 1a**

<table>
<thead>
<tr>
<th>Turf</th>
<th>Astroturf short pile indoor new</th>
<th>Worn Fieldturf outdoor dry</th>
<th>Worn Fieldturf outdoor wet</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum shank acceleration (g)</td>
<td>29.89</td>
<td>28.7</td>
<td>31.74</td>
</tr>
<tr>
<td>Maximum Pelvis acceleration (g)</td>
<td>5.79</td>
<td>4.32</td>
<td>5.31</td>
</tr>
</tbody>
</table>

**Table 1b**

<table>
<thead>
<tr>
<th>Turf</th>
<th>Artificial turf medium pile indoor new</th>
<th>Artificial turf medium pile outdoor dry</th>
<th>Artificial turf medium pile outdoor wet</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum shank acceleration (g)</td>
<td>31.38</td>
<td>30.28</td>
<td>34.54</td>
</tr>
<tr>
<td>Maximum Pelvis acceleration (g)</td>
<td>3.99</td>
<td>3.85</td>
<td>5.04</td>
</tr>
</tbody>
</table>

**Table 1c**

**Table 1a-c: Maximum Shank and Pelvis accelerations on turfs during 45-degree turn to the right**

The maximum shank and pelvis accelerations occurring during heel strike while making a 45-degree turn to the right show similar values on all seven turfs. The maximum acceleration occurring on natural turf is 32.9 g at the shank and 3.93 g at the pelvis for the long grass non-drained pitch and 35.3 g at the shank and 5.07 at the pelvis for the short full drained grass pitch - a 7.29% difference at the shank and 29% at the pelvis. The difference may be explained by the hardness of the short grass pitch due to full drainage. The new Fieldturf seemed to be very similar to a long grass pitch, 0.1% difference at the maximum shank accelerations and 4.2% at the pelvis.

The worn Fieldturf and worn medium pile turf seemed to have higher maximum accelerations at wet than dry conditions. At wet condition the footballer was going slower than on the dry pitch in order not to slip especially during a 45-degree turn to the right. The wet condition obliged the athlete to reduce the speed of execution during the turn, making the heel strike longer while applying a greater load on the ground. There is 11% difference at the shank and 22.9% difference at the pelvis on the worn Fieldturf and 14% difference at the shank and 30.95% difference at the pelvis on the worn medium pile turf.

Over the three new artificial turfs, the Fieldturf has the highest value for the maximum shank acceleration at 32.87 g compared to 31.38 g for the medium pile turf and 29.89 g for the Astroturf short pile. The difference is however negligible. The Astroturf has the highest maximum pelvis acceleration at 5.79 g compare to 3.99 g for the medium pile turf and 3.77 g for the Fieldturf. It can be explained by the
The maximum shank and pelvis accelerations occurring during heel strike while making a 45-degree turn to the right show generally similar values on all 7 turfs, the slight differences observed may be explained by the hardness of Astroturf and used artificial turfs, the softness of natural grass and the change in conditions (wet).

The maximum shank and pelvis accelerations were taken during heel strike once full speed was reached.

Figure 2: Shank/Pelvis accelerations on turfs during a 45-degree turn to the right performed at full speed.

Figure 2 shows the pelvis and shank accelerations during heel strike of the football player performing a 45-degree turn to the right at full speed on natural long slightly wet grass, on a new Fieldturf indoor and on a worn Fieldturf outdoor. The player was asked to push from the left foot while making the 45-degree turn to the right. The graph corresponds to the heel strike of the left foot while making the 45-degree turn. As shown previously the shape of the graphs seem very similar on the three surfaces.

Figure 3 shows the pelvis and shank accelerations during heel strike (data recorded over 0.4 s) of the football player performing a full speed run on natural long wet grass, on a new Fieldturf indoor and on a worn Fieldturf outdoor. The athlete was asked to perform at full speed to simulate a run during a football match; the run was over a distance of 30 yards from a stop position. The maximum shank and pelvis accelerations were taken during heel strike once full speed was reached.

Figure 3: Shank/Pelvis accelerations on turfs during running at full speed.

The shape of the graph for the shank and pelvis accelerations during heel strike while running is similar under the three different turfs, the lower value on the outdoor Fieldturf may be explained by its worn condition. The Fieldturf is half filled with sand first and then rubber, under manufacturer specifications. The worn Fieldturf may be assumed to be softer than a new Fieldturf because the infill was minimum and more compressed and the fibres were flattened due to extensive use. There seems to be no difference between a new Fieldturf and a natural grass pitch.

<table>
<thead>
<tr>
<th>Turf</th>
<th>Natural long grass</th>
<th>Natural short grass</th>
<th>New Fieldturf indoor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum Shank acceleration (g)</td>
<td>15.74</td>
<td>14.6</td>
<td>16.34</td>
</tr>
<tr>
<td>Maximum Pelvis acceleration (g)</td>
<td>4.18</td>
<td>8.51</td>
<td>8.57</td>
</tr>
</tbody>
</table>

Table 2a

<table>
<thead>
<tr>
<th>Turf</th>
<th>New Astroturf Short pile indoor</th>
<th>Old Fieldturf outdoor dry</th>
<th>Old Fieldturf outdoor wet</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum Shank acceleration (g)</td>
<td>20.4</td>
<td>11.2</td>
<td>14.27</td>
</tr>
<tr>
<td>Maximum Pelvis acceleration (g)</td>
<td>5.79</td>
<td>8.64</td>
<td>7.29</td>
</tr>
</tbody>
</table>

Table 2b

Table 2a-b: Maximum Shank and Pelvis accelerations on turfs during a run at full speed

filtered accelerations of the footballer during heel strike performing a run full speed on the five different turfs: natural long and short fully drained grass, both being naturally wet, a new Astroturf short pile sand infill (with rubber underlay), new Fieldturf indoor, worn Fieldturf
outdoor under wet and dry conditions. The Tables 2a, 2b summarize the maximum pelvis and shank.

The new Astroturf has the highest maximum shank acceleration. This short pile turf is fully filled with sand therefore has the highest hardness. The worn Fieldturf has the lowest because it can be assumed to be the harder due to minimum infill and compression of the fibres. The accelerations seem to be similar between the new Fieldturf and the short grass pitch fully drained (used for football) during a full run speed.

Figure 4

Figure 4: Shank/Pelvis accelerations on turfs during a “run and stop”

Figure 4 shows the pelvis and shank accelerations during heel strike (data recorded over 0.4 s) of the football player performing a “run and stop” on natural long wet grass, on a new Fieldturf indoor and on a worn Fieldturf outdoor. The athlete was asked to run full speed and make a quick stop. A successful trial was defined when the forward momentum of the subject had come to rest within two steps of the initial stopping action performed on the left foot.

The shape of the graph for the shank and pelvis accelerations at heel strike during a “run and stop” is similar under a new and worn Fieldturf. The corresponding maximum shank acceleration is around 18 g and 5 g for the pelvis. The graph for “run and stop” performed on natural grass shows lower values for both the shank and pelvis accelerations, at a maximum shank acceleration of 13 g and 1.2 g for the pelvis. The test was performed on a natural long grass naturally wet. The pitch was quite muddy when the tests were performed, therefore very soft, providing a high cushioning of the surface, which explains the low values. By comparison another set of tests was performed on a natural short grass fully drained and the maximum shank acceleration during the “run and stop” by the same athlete was 17.87 g and 1.31 g for the pelvis acceleration.

The low value of the pelvis acceleration can be explained by the natural softness of the grass, therefore high level of cushioning, during this specific movement.

The Tables 3a, 3b summarize the maximum pelvis and shank filtered accelerations of the footballer during heel strike performing a “run and stop” on the five different turfs: natural long and short fully drained grass, both being naturally wet, a new Astroturf short pile sand infill (with rubber underlay), new Fieldturf indoor, worn Fieldturf outdoor under wet and dry conditions.

The new indoor Astroturf has the highest maximum shank acceleration as it is assumed to have the highest hardness. The values found on the natural long grass pitch are the lowest because the turf was soaked providing extra cushioning. The footballer was stopping very abruptly because of the muddy aspect of the pitch. The values found on the worn Fieldturf under wet condition are very high due to a reduced speed and a longer stopping phase due to the wetness of the turf, in order not to slip.

The Tables 3a, 3b summarize the maximum pelvis and shank filtered accelerations of the footballer during heel strike performing a “run and stop” on the five different turfs: natural long and short fully drained grass, both being naturally wet, a new Astroturf short pile sand infill (with rubber underlay), new Fieldturf indoor, worn Fieldturf outdoor under wet and dry conditions.

The new indoor Astroturf has the highest maximum shank acceleration as it is assumed to have the highest hardness. The values found on the natural long grass pitch are the lowest because the turf was soaked providing extra cushioning. The footballer was stopping very abruptly because of the muddy aspect of the pitch. The values found on the worn Fieldturf under wet condition are very high due to a reduced speed and a longer stopping phase due to the wetness of the turf, in order not to slip.

The Tables 4a, 4b summarize the maximum shank and pelvis accelerations of the same movements on the same turfs of another football player. The shank accelerations found are much higher than the ones of the first footballer. The video showed a faster pace during the run for the second player and a quicker stop due to higher deceleration. The
footballer emphasized the stop action by targeting a specified area to stop (force plate for the new indoor Astroturf, Fieldturf), therefore increasing the shank acceleration. However the shank accelerations are quite similar for the natural grass pitches and the worn outdoor Fieldturf.

**SUMMARY**

The different activities performed under playing conditions show that the maximum accelerations of the shank and pelvis experienced by the athletes are similar under natural grass and artificial turf, especially with Fieldturf, the new third generation of turf, designed for football and American football under all playing conditions with a high drainage. Fieldturf was developed with the idea to eliminate the rubber underlay and get the additional cushioning from the shock absorbing infill of sand plus rubber. The fibres have the same thickness and density of natural grass with the idea to allow athletes to slide, pivot and turn like they would on natural grass.

Performing sports activities such as a run, a turn and a quick stop on both natural and artificial turf is definitely useful to characterize artificial playing surfaces. Knowing the biomechanical properties of athletes is essential in the development of artificial turf in order to find the right compromise between an increase in pace while providing the maximum protection for the players. Although information on accelerations provides evidence of only one aspect of the biomechanically complex sporting activities studied, it is likely that accelerations will be correlated with injury risk. The similarity in accelerations for the different turfs suggests that the players adopt similar motion pattern strategies and therefore will be exposed to similar injury risks and severity.

Additional tests have been carried out on sports activity movements such as a 90 degree turn to the right, left, a 180 degree turn to the right, and two specific sports movements on all the turfs to confirm the similar motion pattern. The tests were performed by field hockey, football and rugby players to have a wider range of accelerations, motion patterns and the transfer of acceleration on the limb from athletes with different sizes, morphologies and skills.

The accelerations and motion patterns will provide very valuable information in the design of artificial turfs for specific sports with injury and comfort as primary concerns.

**REFERENCES**

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www.espn.com

**ACKNOWLEDGEMENTS**

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