INTRODUCTION

The increasing number of teenagers and adults playing sports such as football, tennis, American football, or field hockey, driven by the need to exercise, to stay fit, to train harder and longer to become professional, or as part of a team practice, have resulted in more frequent use of professional pitches. Even though many sports were developed and are still played on natural surfaces, and especially grass, the intense and extensive use of these surfaces had led to the development of artificial turfs, specifically designed for a wider access, for economic and climatic reasons (cheaper maintenance fee, use under all weather conditions), and to speed up the game. However the development and introduction of artificial turfs has raised strong concerns over sports injuries (knee, ligaments, ankles, foot), especially injury frequency and the severity of those injuries.

Artificial turfs have been developed to enhance players’ satisfaction and comfort while reducing injuries, but there is an ongoing discussion between those who claim that there are a lot more injuries suffered by the athletes playing on artificial turf and those who do not think that there is a significant increase of injuries between playing on natural grass or on artificial turf.

The most common methodology used to assess the mechanical properties of surfaces is based on the German DIN standards for sports surfaces. The Berlin “Artificial Athlete” has been designed to measure the shock absorption of sports surfaces, whether natural or synthetic. The Berlin athlete is a drop-weight tester, used as a two-mass swinger. It measures the impact absorption of playing surfaces, and the peak forces after impact. The force recorded by the transducer is calculated against a reference surface, which has minimal shock absorbency in order to measure the percentage of force reduction, known as the hardness of the surface.

The Berlin athlete is a modification of the Stuttgart Artificial Athlete. Both devices measure the reaction force and the energy absorption of the surface under specific impact time, however the contact time of the Stuttgart Artificial Athlete ranges from 100 – 200 ms compare to the 10 ms for the Berlin Artificial Athlete. The basic test is in need of improvement and standardisation. Tests on an AstroTurf were carried out with a drop-weight impact tester and a servo-hydraulic tester with the aim of being more accurate by taking into account the biomechanics of the athletes, testing the turf under load experienced by athletes during sporting activity.

METHODS

Two sets of apparatus were used to perform compression tests on artificial turf with the idea of integrating the biomechanical properties of athletes and mechanical properties of artificial turf under playing conditions. The first series of tests was carried out using a servo-hydraulic tester, ZWICK compression/tension model ‘2061’ (Figure 1).

The AstroTurf was used under playing condition, with a rubber underlay (10 mm) underneath and filled with sand described as washed and graded high silica sand. It had a fibre thickness of 15 mm and a density of 44,000-stitches/spm, and is primarily used for tennis.
of 0 N with the same time rate, the plate was then released, by moving downwards (stroke controlled).

The servo-hydraulic tester was linked to a computer. The set up for the different testing were entered directly from the computer using the Interface software. The threshold load increment and stroke increment were then defined. In the tests the load increment was 25 N with a stroke increment of 100 micrometers.

The second series of tests was carried out with a drop-weight impact tester, Rosand Instrumented Falling Weight Impact Tester Type 5 (Figure 2).

![Figure 2: Rosand Instrumented Falling Weight Impact Tester Type 5.](image)

The turf and the underlay, in the same box, were placed inside the impact tester on the lower plate. A 30kg load with a hemispherical test probe with a 50 mm diameter on the bottom was attached to the drop-weight. The test is specified by the energy of impact in joules. The control system automatically adjusts the height of the drop to give the described energy. The energy can therefore be adjusted to give any peak load.

In order to simulate the athlete's activities the final loads ranged from 1000 to 5000 N, representing the impact load of a person jogging (2 body weight), running (2.5 – 4 body weight) or jumping (5 – 7 body weight), with an impact time of 50 ms, corresponding to the impact time of heel strike.

**RESULTS AND DISCUSSION**

Tests performed with the servo-hydraulic tester included impact time of 250 ms, 500ms and 1 s. Tests with the drop weight were performed with an impact time of 50 ms, which is approximately the impact time during heel strike.

![Comparison force deflection with Drop weight / Servo-hydraulic tester on artificial turf](image)

**Figure 3: Comparison of the Load/deflection curve of the artificial turf under an applied load using the drop-weight and servo-hydraulic testers.**

Figure 3 shows the load / deflection curve of the artificial turf with the two tests. In both curves the applied maximum load is 2500N, which corresponds to the load applied during running (3 bodyweight). The impact times are 50 ms for the drop weight test, 250ms with the servo-hydraulic test.

The total thickness of the turf was approximately 25 mm (10 mm for the underlay and 15 mm for the artificial turf). The maximum deflection of the turf under the load is 6mm with the drop weight tester, and 9.5mm with the servo-hydraulic tester, which shows a difference of 58%.

Even though the fibres of the turf cannot be expected to be uniformly distributed the difference appears to be due to the different impact time of the two tests.
Figure 4: Comparison of the linear trends of the maximum deflections of the turf at different peak loads using the drop-weight and servo-hydraulic testers.

Figure 4 shows the deflection of the turf while applying different loads (1kN to 4.5kN) corresponding to walking, running, and jumping. With the drop-weight tester the turf reached a maximum compression of 7.5 mm at a load of 3000 N, beyond this level of loading no further compression was observed. With the servo-hydraulic tester the maximum compression of the turf was 11.5 mm at a load of 3500 N. For greater load no changes in deflection were observed, in fact the turf had “bottomed out”.

At around 2500 N (3X body weight, load applied during running) the deflection of the turf was 6.3 mm with the drop-weight tester and 9.5 mm with the servo-hydraulic tester, consequently the deflection found with the servo-hydraulic tester is 50.7 % greater than the one found with the drop-weight tester.

Figure 5 shows the energy absorption of the turf with the two testers as a function of deflection. It is calculated using the integration from the load - deflection data. To get the energy absorbed first all the area was determined using a numerical integration

The servo-hydraulic tester showed a lower energy absorption value than the drop-weight under the same deflection. The results were quite different mainly because of the impact time of the two testers (50ms for the drop-weight, 250ms for the servo-hydraulic). The drop-weight showed more accurate and realistic results because the full load is applied in 50 ms, which is comparable to the impact time during heel strike while running.

Figure 5: Comparison of the linear trends of the energy absorptions at maximum deflections of the turf using the drop-weight and servo-hydraulic testers.

The tests carried out with the servo-hydraulic tester showed scattered results, while not following closely the linear trend, especially under high turf deflection. The best fit linear correlation factor was found to be low at 0.682. The results found with the drop-weight tester seemed to follow a linear trend under low energy absorption, but above 6 J the results are scattered. The correlation factor was 0.82.

Some of the energy absorbed by the surface is returned to the athlete during the take off phase. Most of the energy is lost as deformation in the carpet. The balance between energy returned and energy loss plays an important part in the development of a surface.

For an energy absorbed of 6 J, the corresponding maximum deflection of the turf found using the drop weight tester was 6 mm, and 9 mm with the servo-hydraulic tester. At 7.5 mm, the maximum deflection of the turf with the drop-weight, the corresponding energy absorbed was 9 J. At the maximum deflection of the turf found with the servo-hydraulic tester, 11.5 mm, the corresponding energy absorbed was 14J, representing a 55.5% difference between the two testers.

Figure 6 shows the energy absorbed by the turf while applying different peak loads with the two testers. The energy absorbed by the turf and the energy returned during take-off phase plays an important factor in the design of the next generation of turf in terms of energy cost during sports activities, and the reduction of excessive loading.
DISCUSSION OF THE BERLIN ATHLETE

Artificial turfs are constructed with the intention to reduce excessive loading, improve performance and reduce injuries, or severity of injuries. Energy absorption and return of the turf is essential as well for all the reasons listed above.

The method commonly used to characterise the mechanical properties of turfs is the Berlin athlete. The Berlin athlete is a drop weight that may be modelled as a 2-mass, 2-spring system. It is made of metal, therefore has a low damping and high mechanical noise degrading the signal. The Berlin athlete, shown schematically in Figure 7, consists of a 20kg mass, that is dropped from 55mm with an impact time of 10 ms on to a circular flat foot of 1.8 kg that includes a spring of 2 MN/m stiffness, through which the impact is applied onto the surface, with a 70 mm diameter test foot and a bottom surface with a radius of 500 mm.

Figure 7: Schematic of the Berlin Artificial Athlete

The force produced by the Berlin athlete is typically 6.3 kN on concrete, and 4.2 kN on artificial turf (Dunlop, J., 2000), compared to the force applied on the ground during running which is around 3 bodyweight, or 2.5kN. The force recorded by the transducer is calculated against a reference surface, which has zero shock absorbency in order to measure the percentage of force reduction, known as the hardness of the surface. The FIH (Federation International of Hockey) has set a force reduction between 40 and 65%. The FIFA (Federation International Football Association) has set it between 55 and 70%.

While this force reduction appears to be realistic to measure the surface resilience, several factors make it not relevant for the new artificial turfs. The Berlin athlete was developed for hard surfaces such as gymnasium floors, track and field surfaces, since the force-deflection curve of such hard surfaces are linear and elastic. However artificial turfs, and all outdoor surfaces have a non-linear force-deflection curve.
and have visco-elastic properties. The Berlin athlete would have to change the settings to provide relevant standards to categorize artificial surfaces.

THE BERLIN ATHLETE AS A SECONDARY STANDARD

At present the Berlin athlete is used as an absolute standard on its own. It is clear from the tests that the artificial turf shows non-linear and visco-elastic properties. Under these circumstances, the Berlin athlete cannot be held to provide test data that is of direct relevance to the athletes that use the pitches. It may proceed in an alternative manner as follows: The height from which the load is dropped should be modified until a peak force of approximately 2.5 kN is obtained, corresponding to the force experienced by the athlete while running.

The second modification involves the 70 mm test foot, knowing the human heel has a diameter of around 50 mm, the indentation of the foot into the surface is area contact (the compression of the area under the foot is uniform), unlike the heel impact which is point contact, (the compression of the surface is greatest close to the middle of the heel area, and less at the edges). The third modification involves the impact time of the heel on to the playing surfaces (50 ms). The Berlin athlete operates with a resonant frequency of 50 Hz, with a whole impact time of 10 ms, while it should be operating at around 10 Hz. Making the spring less stiff would bring the resonant frequency down.

The Berlin athlete should be used as a secondary standard, to enable a comparison between the playing surface and a reference surface. The force reduction given by the Berlin athlete does not give any information on how the athlete’s legs are responding to the playing surfaces despite still being the standard in characterizing playing surfaces.

CONCLUSION

38 trials were performed with a servo-hydraulic tester and a set of 33 with a drop weight tester to have a clear understanding on how the turf reacts under different loading and impact timescales. The test carried out with the drop weight impact tester offers a better alternative, providing the correct impact time, and the possibility to change the applied load (ranging from 2 to 8X bodyweight, corresponding to different sports activities), allowing study of the properties of the turf under the loads applied by athletes, therefore taking into account the bio-mechanical properties of athletes.

An alternative method has been proposed using the Berlin athlete as a secondary standard.

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ACKNOLEDGEMENTS

The Engineering and Physical Science Research Council (UK) for funding this project.

Mr Andrew Crockett from the University of Strathclyde for his help and time devoted during all the tests carried out on both testers.