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Impact Isolation of Training Shoes

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ABSTRACT

The increase in popularity of physical activities from fun runs to competitive marathons has lead to a huge industry in sports footwear, which is now worth $20bn annually. There is a resultant increase in injuries, largely due to the repeated and prolonged nature of the impact forces experienced by the leg. Clinical data indicates that the knee is the most common site of running related injury, followed by the lower leg and foot. The complexity of the ankle structure means that injuries are acute and the success rates of replacements are very low. Therefore research in this area is required; to understand both the nature and magnitude of the loads the ankle is subjected to while walking and running, and how these loads may be minimised.

This paper investigates the effectiveness of four different running shoes, ranging from a low cost department store own branded shoe, to a high cost specialised running shoe. The shoes are tested on a custom built drop test rig, which can drop the shoes while fitted to a prosthetic foot and ankle. The shoes are dropped to simulate the impacts that occur while walking and running. The rig allows for a range of drop heights, and the ankle to be positioned at various angles to replicate heel strike, flat foot and toe strike. The rig is fitted with force transducers and accelerometers, to record deceleration, and ground reaction force. Also the impacts are recorded on a high speed camera for analysis; this yields the impact velocity, energy absorption and deformation.

KEYWORDS: (Impact, Isolation, Running, Shoe)

1. INTRODCUTION

Training shoes have become a $20bn industry worldwide [1], yet there is very little quantitive information on the effectiveness of various shoes. Shoe manufacturers make wide ranging and generalised claims about the performance of various shoes, but do not make test data, or even the nature of the test available. This project sets out to determine the effectiveness of training shoes to protect the lower limbs from the impact forces that arise during walking and running. The project does this through the following stages:

- Development of a test that can simulate the impact forces while walking and running.
- Impact testing four different shoes, ranging from low cost to specialised shoes.
- Comparison of data with other published data.
- Investigation of the shoe components that provide impact protection.

The project does not investigate the gait cycle as there has been considerable work in this area.

1.1 BioMechanics of the Ankle

The ankle is constructed as a hinge joint and is the primary junction between the leg and the foot. The bones that make up this joint are the tibia and the talus which lies in the vertical weight bearing axis of the leg between the tibia and the calcaneus. Figure 1 shows how complex the ankle structure is, consisting of a series of highly integrated joints. This complexity means reconstruction or replacement in has not been very successful, therefore protecting these joints as much as possible is extremely important to prevent injury and surgery.

Figure 1: Ankle Physiology [12]

1.2 Ground Reaction Force

Ground reaction force (GRF) is the reaction when the foot strikes the ground while walking or running. There are horizontal and vertical components to this force, but the vertical component of the force is of relevance in this study. This component has the largest contribution in the overall GRF and can be seen to be the least variable among studies. Cavanagh & Lafortune [2] and Logan [3] found that the vertical force can reach up to three times a person's body weight. The vertical ground reaction force is affected by body mass, mass distribution, running style, area of foot ground contact, shoe material properties as well as foot mechanics. In a study by Liebermann et al at Havard [4] it was found that vertical ground reaction force produced a transient peak force of 1.6 (as a proportion of body weight) which is 1100N (body weight 70kg) as shown in Figure 2.

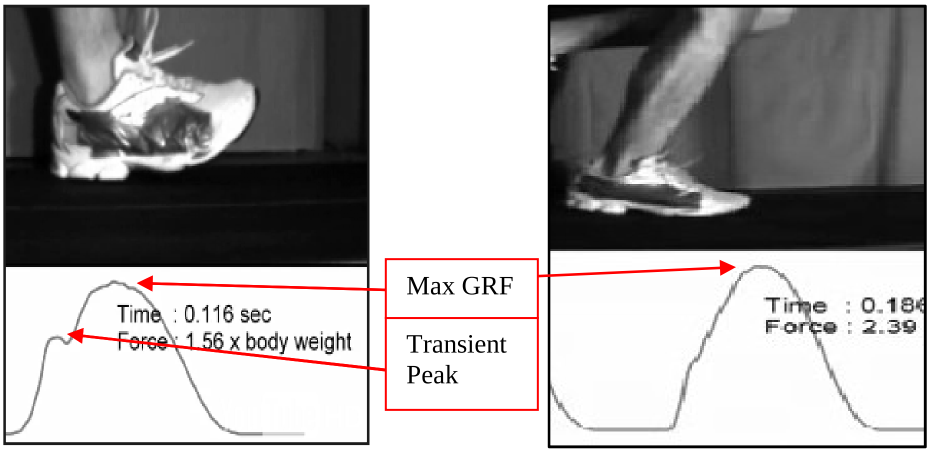

Figure 3: Toe Strike [4]

They found the maximum reaction force is 2.4 times body weight (1650N for a body weight of 70kg). The ratio of the first impact peak to the maximum is 1.5, this is used in this study to calculate maximum GRF from the impact GRF measured. Liebermann et al at Havard [4] also found that toe strikers (Figure 3) do not experience this initial transient peak. The running velocity is found by comparing the maximum peak with studies by Chui [5], Nillson [6], and [3], from these it was found that the maximum GRF is equal to 0.464 times running speed, these authors agree that this linear relationship exists up to running speeds of 4m/s. However there is some disagreement over whether GRF is a good predictor of potential injury [7].

1.3 Running shoes effect on Ground Reaction Force

When jogging, 86% of people heel strike first [3]. The remainder toe strike first, also it should be noted that when people run barefoot their running style is different and they generally become toe strikers (this is thought to be the reason for the lack of impact injuries in barefoot runners [8]). Also when changing from jogging (heel strike) to a fast run (6m/s) people's style changes from heel strike to toe strike [9]. As most people heel strike when jogging, training runners are designed to minimise the initial transient peak, by reducing the deceleration and also by increasing the area of the heel strike.

The effective mass is known as the mass involved for whatever portion of the body comes to a dead stop along with the point of impact on the foot. Since the impact occurs over a short period of time the force multiplied by the duration of the collision, called the impulse, is the effective mass multiplied by its change in velocity over the duration of the impact.

The effective mass during heel strike is the foot plus the lower leg and Liebermann et al [4] found the effective mass to be 6.8% of total body mass. For toe strike the effective mass equals 1.7% of the total body mass, it is thought that it is this lighter effective mass that also may make barefoot running less prone to ankle injuries [8].

2. TESTING

Figure 4 below shows the rig that was used for testing. The rig was initially setup as a mechanical drop test machine for analysing the properties and effects of a bicycle helmet when subjected to an impact test. A range of drop heights can be used and the shoe can be set at a variety of angles to simulate both heel strike, flat foot and toe strike. The rig is instrumented to measure ground reaction force (Kistler 9712B500 force transducers) and deceleration (Kistler 8630C50). These are linked to a DAQ card and the results are recorded (at 20kHz) and viewed using Labview. The combined weight of the test piece and the drop head including the shoe is 7.4kg, this represents the effective mass of the lower leg while running or walking.

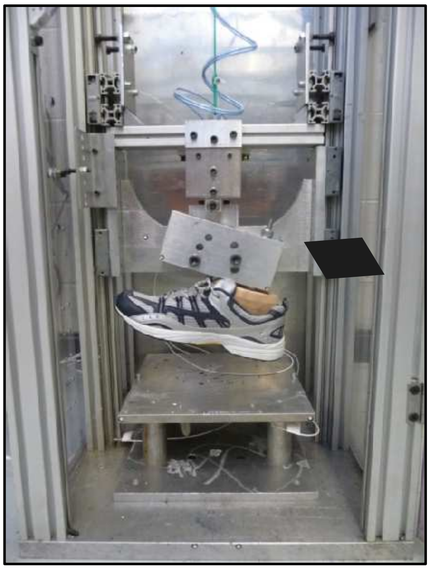

Figure 4: Test Setup

In addition the tests are recorded using a high speed camera (Photron 1024pci, at 2000 frames/second) and the videos are analysed using TEMA software to determine impact velocities, and deformation. The shoes selected for testing are:

- top end specialised training shoe
- mid to high (mid/high) end market training shoe
- mid market training shoe
- low cost own branded department store shoe

The following drop heights were used:

Drop Height	Jogging Speed			Impact Vel	Impact Energy
mm	m/s	km/hr	mph	m/s	J
55	2.1	7.5	4.7	1.04	3.99
65	2.5	9.1	5.7	1.13	4.72
75	2.8	10.0	6.3	1.21	5.44
85	3.0	10.8	6.8	1.29	6.17
100	3.3	11.9	7.5	1.40	7.26

Table 1: Drop Heights

2.1 Shoe Construction

The low cost shoe does not make any claim that it is a performance running shoe, unlike the other three shoes. It can be noted from its construction (Figure 5) that there is no high density material present in the heel, hence it will be comfortable at low impacts but will collapse with high impact energies. In contrast to this the mid/high cost shoe heel (Figure 6) is constructed from a double layer of foam material and an EVA (ethylene and vinyl acetate) insert.

Figure 5: Low Cost Heel

Figure 6: Mid/High Cost Heel

3. RESULTS

Four shoes were tested at five drop heights and three angles, each experiment was repeated twice for consistency. In addition 15 tests were carried out without a shoe as a benchmark. Therefore a total of 135 tests were completed. This paper will discuss the results for heel strike only as they are the most relevant for joggers.

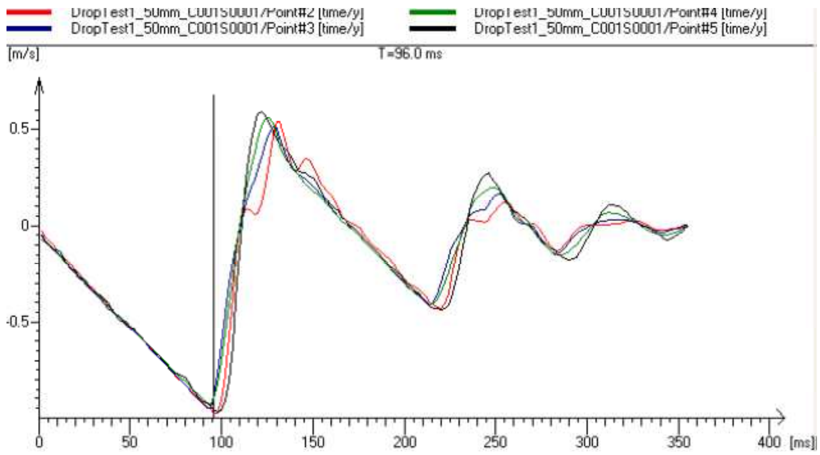

Figure 7: Typical Test result from high speed video (Velocity Vs Time)

During heel strike the ground reaction force was measured (Figure 8), it should be noted that this represents the initial peak force that is experienced during heel strike (not the maximum GRF). The 3 specialised running shoes performed in a similar manner whereas the low cost shoe had a GRF of approximatly 10% higher across the range of impacts. GRF is not considered to be a significant indicator of injury hence this difference was not considered significant.

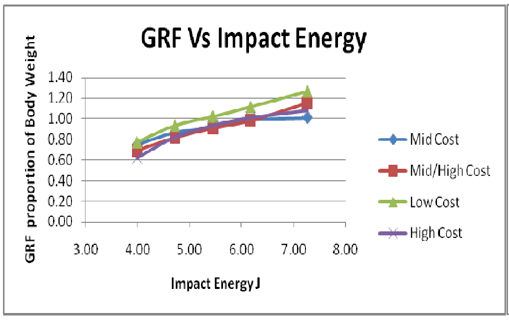

Figure 8: Ground Reaction Force

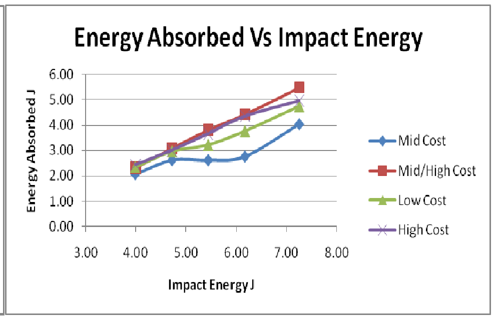

Figure 9: Energy Absorbed

The energy absorbed was also measured; this was calculated as the difference in the impact kinetic energy and the re-bounce kinetic energy (Figure 9). Here the mid/high cost shoe and the high cost shoe performed in a similar way, whereas surprisingly, the mid cost shoe did not perform at all well with an energy absorption of 35% less than the better shoes. The low cost shoe performed reasonably well, but whether it would perform well at higher impact energies is unknown.

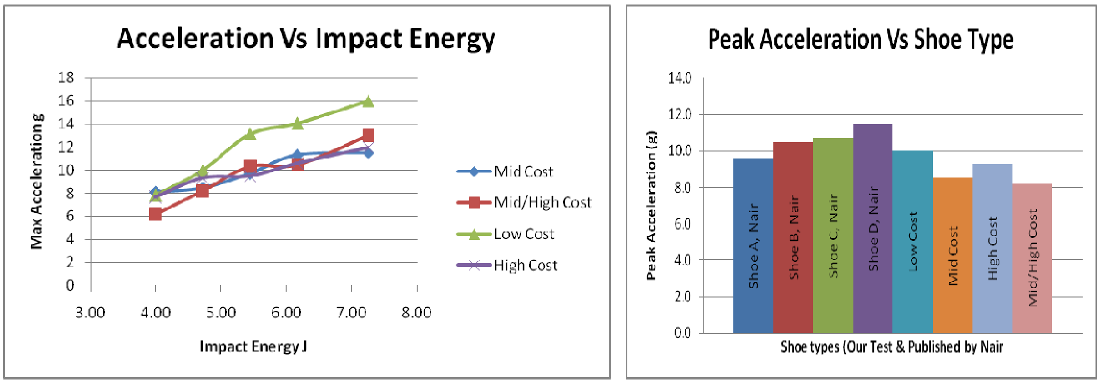

Figure 10: Peak Acceleration

The most significant criteria that was measured was the deceleration experienced (Figure 10) by the shoe on impact. This is considered significant as Newton's 2nd law states that force is proportional to acceleration. Here the low cost shoe's performance was the worst by far showing accelerations of up to 45% higher than the other shoes. This would indicate that wearing this shoe would result in impact forces of 45% higher than while wearing the other shoes. Again the three other shoes performed in a similar way. The differences in the acceleration values are directly related to the use of high density foams in the heel of the shoe in the three specialised shoes. Figure 11 shows a comparison with peak accelerations measured by Nair and Marshall [10], these are similar to those measured by ourselves, with the 3 specialised running shoes measuring lower decelerations. Nair and Marshall [10] do not give details of the types of shoes they tested.

4. CONCLUSION

The ground reaction force measured during testing ranged from 0.62 times body weight at a running speed of 2.1 m/s to 1.27 at a running speed of 3.3m/s. This is the initial peak on impact during heel strike. For the largest impact (7.26J) the GRF for the low cost shoe was 1.27 while for the mid cost shoe it was 1.01. As the GRF is not considered to be a reliable predictor of injury this was not considered significant [7].

Accelerations ranged from 16g (low cost shoe) to 11.5g (mid Cost) during an impact from a drop height of 100mm (impact energy 7.26J). This is considered significant (39% increase) as this could be considered a predictor of injury [10]. The low cost shoe performed particularly badly, when examined it was found that the heel consisted of a series of voids, where as the other three shoe's heels were manufactured from a high density foam, in some cases with a high density insert.

The mid/high cost shoe performed best when the energy absorbed was examined. This shoe also had a linear response over the range of impacts and consistently absorbed more energy than the other shoes. This shoe was launched in October 2010 and the manufacturer claims that this shoe uses the latest technologies to provide greater performance. It should be remembered that although energy absorption may minimise the risk of injury it will probably affect running performance negatively, hence when racing, athletes wear racing flats or spikes which provide very little absorption [3].

Overall while the type of shoe is important in particular for jogging, (at walking speeds impact forces are low, while at fast running speeds runners toe strike), the running style is of more consequence than the shoe. If runners were to flat foot or toe strike, the transient peak could be avoided with the added benefit of spreading the force over a larger area hence reducing the impact stress.

It should be noted that the test carried on as part of this project were not carried out in accordance with any standard or on certified equipment. Also only one aspect of the shoe was investigated (impact isolation), important aspects such as stability were not considered.

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