Impact force characteristics in Healus™ footwear in comparison with conventional running shoes

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Introduction

In recent years running has become a popular physical and recreational activity. Running is a convenient low cost pass time, which contributes to a decreased mortality rate, as well as a reduction in morbidity and the development of disabilities in older adults (Curfman 1993 and Sadvick et al. 1993). Unfortunately however, epidemiological studies analysing the prevalence of running injuries suggest that overuse injuries are a prominent complaint for both recreational and competitive runners (Hreljac 2004). The principal risk is cyclic impact loading, but excessive subtalar joint pronation can also contribute to increased risk of injury (Edington et al. 1990).

Typical distance running speeds may result in as many as 300 foot strikes per leg per kilometre, often on hard surfaces (Valiant 1990). The interaction between the foot and ground during each foot strike generates a transient shock wave that is transmitted through the musculoskeletal system (Shorten 2000). There is considerable evidence to suggest that transient forces are harmful (Whittle 1999). Repeated impact loading of the body during gait has been linked to the development of degenerative osteoarthritis (Radin et al. 1972, Radin et al. 1991, Yiling et al. 2000 and Dekel and Weismann 1978), lower back pain (Voloshin and Wosk 1982), tendinitis (Lysholm and Wiklander 1987 & Van Mechelen 1992) and stress fractures (Watson and Di Martino 1987).

Attenuation of vertical force parameters has been the main concern for footwear manufacturers, as one of the primary roles for running shoes is to offer cushioning (Cavanagh 1980 and Nigg 1986). A large variety of materials have been utilized in the cushioning systems of modern running shoes (Shorten 2000). These may consist of materials such as foamed polymers, viscoelastic materials, air soles, gases, gels and moulded springs (Lake 2002).

In vivo analyses have revealed that shoe-cushioning mechanisms do not influence impact force parameters (De Wit et al. 1995). It is hypothesized that the cushioning properties of modern footwear create a perceptual underestimation of impact severity (Frederick 1986).
Under load plantar feedback is important for the perception of impact and neuromuscular adaptations in kinematics. Thus, wearing shoes with cushioning systems may reduce this plantar sensory mechanism, resulting in a sharp reduction in shock attenuating behaviour (Frederick 1986).

Another potential contributor to overuse injuries during running is excessive rear foot pronation. Pronation is a natural component of normal gait mechanics. At the end of the swing phase, the foot is in a supinated position, as the opposite limb adducts under the body, this tilts the foot so that ground contact occurs via the lateral border of the heel or midfoot (Sammarco 1980). Although pronation combines both eversion and abduction of the foot via subtalar rotation and ankle dorsiflexion, the principal component of pronation is eversion of the calcaneus, which is traditionally measured by 2-D kinematics (Shorten 2000). Significantly the subtalar joint is orientated in a way that links eversion to internal tibial rotation via the mitered hinge effect (Czerniecki 1988). The relationship between pronation and tibial rotation is hypothesized to significantly contribute to running injuries (Shorten 2000).

Previous investigations have demonstrated that the impact shock during landing when running is principally determined by the movement strategy adopted by the runner (Hartveld and Chockalingham 2003). Based on these observations a new type of running shoe the Healus™ technology has been developed. The aim of the Healus™ shoe is to induce kinematic adjustments that will in turn facilitate positive alterations in kinetics (Hartveld 2005, 2006a, 2006b & 2006c). The Healus™ technology incorporates a compliant slant sole, which is designed to promote a more plantar flexed ankle on contact (Hartveld 2005, 2006a, 2006b & 2006c). The rationale behind this plantar flexion movement during the stance phase can provide a more appropriate deceleration of the body hitting the ground, thus decreasing the vertical ground reaction force parameters on foot strike (further explanation and image of Healus™ technology is available at www.healus.co.uk/).

The aim of the current study is to provide a comprehensive description of Healus™ running using a statistical representative data set, and to compare Healus™ and conventional shod running. Therefore, ground reaction forces and rearfoot kinematics during the stance phase of running will be analysed and compared; thus allowing adaptations in the kinetics and kinematics of running to be detailed.
Given the nature of the shoe design and taking into account previous research, it is hypothesized that the Healus™ footwear significantly lowers vertical GRF parameters.

Method
Participants
Ten male participants with varied running experience volunteered to take part in this study. All were injury free at the time of data collection and completed an informed consent form. The mean characteristics of the participants were; Age 19.90 + 1.10 years, Height 178.10 + 5.20 cm and mass 76.79 + 8.96 kg. The procedure was approved by the Psychology Ethics Committee, University of Central Lancashire.

Experimental protocol
Participants were tested whilst running in conventional and Healus™ running shoes, at a velocity of 4.0ms⁻¹. The three orthogonal vectors of the GRF were calculated as participants ran over a Kistler™ force plate (sampling at a frequency of 1000 Hz), mounted flush with the floor at centre of a 20m runway. Recorded forces were normalized to the body weight of the participants by dividing by body weight. Average loading rate was calculated by dividing the impact peak magnitude by the time to the impact peak. Peak loading rate was quantified as the maximum increase in Fz between frequency intervals. Stance time defined as the time that a minimum of 20 N of was applied to the force plate. GRF data was filtered at the source via a 10Hz low pass filter.

Running velocity was quantified using infrared photocells mounted at chest height on both sides of the force plate 2.0 m from the centre of the plate. In accordance with the guideline set by De Wit et al. (2000) a maximum deviation of +5% from the set velocity was allowed. Participants were allocated time in which to complete an adequate warm up and familiarize themselves with the experimental running velocities. Runners completed a minimum of five accepted trials. A successful trial was defined as one within the specified velocity range, with the right foot landing totally on the force plate with no evidence of targeting (Challis 2001). To ensure constant velocity locomotion was observed a key criterion for an acceptable trial was an equal anterior and posterior impulse during stance.
The order in which participants wore the different shoes was randomised, whichever shoe was selected to be worn first all of the necessary trials were completed in that shoe prior to running in the other.

**Figure1:** Experimental Lab set-up

**Motion Analysis**

Motion analysis was carried out using an eight camera Qualisys motion analysis system operating at 350Hz. Reflective markers were placed on the skin overlying anatomical landmarks in such a way that segments could be identified (feet, lower legs, thighs and pelvis). Kinematic parameters were calculated using Visual 3D (C-Motion Inc). Three-dimensional angles were constructed about a segment coordinate system. Angles were created about an XYZ rotation Cardan sequence referenced to coordinate systems about the proximal end of the segment. All marker data were interpolated with a maximum gap fill of 10 frames and low-pass filtered using a fourth order Butterworth filter with cut-off frequency of 3 Hz.

**Shoes**

The shoes were the same for all runners; they differed in size only (sizes 9 and 10 in men’s UK shoe sizes) and consisted of a conventional running shoe (Saucony Grid Tangent 3) and the Healus™ technology.
Statistical Analysis
Given that forefoot or mid-foot strikers characteristically lack an impact peak, to control for variations in foot strike characteristics, only participants with a natural heel-toe gait pattern were included in the data analysis. Differences between the two footwear conditions were analysed using paired samples T-tests with significance accepted at the $p \leq 0.05$ level. All statistical procedures were conducted using SPSS 17.0 software.

Results
Kinetic
Paired t-tests revealed that vertical impact peaks ($t(9) = 2.46$, $p \leq 0.05$) and peak loading rates ($t(9) = 2.47$, $p \leq 0.05$) were significantly $p \leq 0.05$ lower whilst running in the Healus™ footwear compared to the conventional shoe. Paired t-tests for Time to peak impact, Average loading rate, Peak braking force, Peak propulsive force, Peak medial force, Peak lateral force and Stance time between the two footwear conditions did not exhibit significant differences $p > 0.05$.

Table 1: Kinetic and temporal variables (means and standard deviations) as a function of footwear (* = Significant main effect $p \leq 0.05$)

<table>
<thead>
<tr>
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<th>Conventional</th>
<th>Healus™</th>
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<tbody>
<tr>
<td>Vertical Impact Peak (BW)</td>
<td>2.15 + 0.22</td>
<td>1.81 + 0.45</td>
</tr>
<tr>
<td>Peak Loading Rate (BW.s$^{-1}$)</td>
<td>277.32 + 78.80</td>
<td>213.37 + 56.99</td>
</tr>
<tr>
<td>Average Loading Rate (BW.s$^{-1}$)</td>
<td>71.03 + 17.45</td>
<td>62.67 + 17.58</td>
</tr>
<tr>
<td>Time to Peak Impact (s)</td>
<td>0.033 + 0.07</td>
<td>0.03 + 0.08</td>
</tr>
<tr>
<td>Peak Braking Force (BW)</td>
<td>0.47 + 0.10</td>
<td>0.49 + 0.09</td>
</tr>
<tr>
<td>Peak Propulsive Force (BW)</td>
<td>0.28 + 0.26</td>
<td>0.40 + 0.45</td>
</tr>
<tr>
<td>Peak Medial Force (BW)</td>
<td>0.12 + 0.20</td>
<td>0.19 + 0.10</td>
</tr>
<tr>
<td>Peak Lateral Force (BW)</td>
<td>0.14 + 0.11</td>
<td>0.10 + 0.36</td>
</tr>
<tr>
<td>Stance Time (ms)</td>
<td>237.46 + 36.24</td>
<td>232.29 + 35.36</td>
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Kinematic

At initial contact the ankle was significantly more plantar flexed (t (9) = 2.53, p<0.05) in the Healus™ running shoe compared to the conventional footwear. In the coronal plane the ankle exhibited non-significant (p>0.05) increases in peak eversion whilst wearing the Healus™ footwear. In the Healus™ shoe the peak tibial internal rotation angle (although not significantly p>0.05 different) was considerably larger in comparison to the conventional footwear.

Table 2: Selected kinematic variables (means, standard deviations and ranges) as a function of footwear (* = Significant main effect p<0.05).

<table>
<thead>
<tr>
<th></th>
<th>Saucony</th>
<th>Healus™</th>
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<tbody>
<tr>
<td>Ankle</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Angle at Footstrike (°)</td>
<td>-79.69 + 7.12, 24.59</td>
<td>-67.10 + 11.30, 35.18</td>
</tr>
<tr>
<td>Maximum Eversion Angle (°)</td>
<td>-5.49 + 7.13, 21.56</td>
<td>-7.01 + 5.10, 14.50</td>
</tr>
<tr>
<td>Knee</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maximum Internal Rotation (°)</td>
<td>5.36 + 20.42, 78.38</td>
<td>12.57 + 15.94, 54.48</td>
</tr>
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</table>
Discussion

The aim of this study was to provide a biomechanical comparison of Healus\textsuperscript{TM} and conventional cushioned running shoes. Differences in kinetics and kinematics between the two footwear conditions were examined to gain an understanding of the adaptations runners make when running in the Healus\textsuperscript{TM} footwear. Due to the relatively recent launch of the technology running shoes, this study represents the first comparative study concerning the kinetic and kinematic characteristics of Healus\textsuperscript{TM} footwear.

Impact forces are linked to the aetiology of a variety of overuse injuries (Whittle 1999). It is important to acknowledge the relationship between impact forces and overuse injuries, given that the magnitude of these forces and by implication the frequency of injury can be decreased by attenuating the impact magnitude (Whittle 1999).

The Healus\textsuperscript{TM} running shoe is designed to reduce the vertical GRF parameters associated with footstrike. The results of this study support the hypothesis in that the magnitudes of the vertical impact peaks and peak vertical rates of loading were significantly ($p<0.05$) lower in the Healus\textsuperscript{TM} technology shoes compared to the conventional cushioned footwear. This agrees with the findings of Hartveld et al (2005) who reported significantly lower vertical impact peaks and rates of loading when running in the Healus\textsuperscript{TM} running shoes compared with a conventional training shoe. Such loading rate patterns represent the capacity of the running shoes to attenuate the magnitude and rate at which the impact shock is applied to the lower extremities (Logan 2007). These findings lead to the conclusion that the Healus\textsuperscript{TM} technology running shoes have the potential to reduce impact related injuries.

The double peaked GRF time history predominantly exhibited whilst running in the Healus\textsuperscript{TM} running shoe highlights a potential problem when using conventional methods of quantifying the average loading rate. Until such time when the foot-ground interface is modelled appropriately whilst wearing the Healus\textsuperscript{TM} it is difficult to quantify the average loading rate. This study thus further emphasises the conception that peak loading rate is a more appropriate measure than the average loading rate. Peak loading rate is a more suitable measure of the shock attenuation properties of running footwear as it provides a more accurate representation of the transient shock wave associated with foot strike. Future studies may wish to report peak loading rates to quantify the shock attenuation properties of running shoes.
However, whether or not higher impact forces amplify the incidence of overuse, injuries in the lower extremities have been a central subject matter in epidemiological research. Prospective studies are the benchmark for ascertaining cause and effect relationships. More prospective studies are thus necessary where measures are determined before individuals obtain the injury and as such causative factors may be more accurately determined (Taunton et al. 2003).

The manufacturer claims that the Healus™ running shoes can enhance the stability of the subtalar joint during gait, via the Healus™ cupped shock plate and individual sole flares. The Healus™ shoe is designed to guide the foot though the optimal range of motion during running, preventing injuries from excessive pronation. However, the results of this study do not support this hypothesis, in that there were no significant (p>0.05) differences in subtalar eversion magnitudes between footwear conditions. Whilst the difference did not reach statistical significance the data analysis revealed that the Healus™ technology shoe allowed more eversion than the conventional shoe.

In addition the movement coupling between the foot and shank, which results in the tibia rotating internally between touchdown and midstance, is associated with running injuries. Data analysis revealed that whilst the differences did not reach significance, the Healus™ shoe allowed considerably more internal rotation of the tibia compared with the conventional shoe. Increased rotation under loaded conditions may place abnormal rotational stress on the musculoskeletal structures of the knee joint as well as excessive torsional stresses experienced by the tibia itself (Clement et al 1984). These findings suggest that running in the Healus™ footwear may be associated with an increased risk from stability related injury.

Future research should focus on modelling the foot/ground interface when wearing the Healus™ footwear in order to obtain a more meaningful understanding of how the shoe alters running mechanics. The running shoe acts as the primary interface between the runner and the road, and thus has an important role to play in the management of injuries (Shorten 2000). Shock attenuation and stability will always be important features in running shoes and thus it is vital that we obtain a better understanding of how they interrelate to prevent injury.
References


