

**The changes midsole cushioning and running surface have on impacts**

by

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## ABSTRACT

**Introduction:** One of the major factors related to overuse injuries in runners is impact force resulting from the runner hitting the ground at heel strike. (Hreljac et al., 2000). This impact will increase and decrease based on the construction of the running shoe used as well as the type of surface being run on. The purpose of this research was to determine the effects that both midsole cushioning and surface stiffness have on this impact force.

**Methods:** Six recreation runners running at least 10 miles per week ran a 2.2 km course 3 times at a self selected pace. A variable cushioning running shoe (Adidas One®) was used and set in a low cushioning, high cushioning, or self adjusting cushioning mode for each run. Accelerometers were attached at the leg and forehead to measure impacts and impact attenuation. Accelerometer data were sampled at 512 Hz. The course consisted of the following surfaces: cement, asphalt, dirt, gravel, woodchips, sand, grass, and a wooden suspension bridge. Cohen's D formula was used to calculate effect sizes comparing each shoe and each surface. The values 0.5 and 0.8 were used to determine medium and large effect sizes respectively.

**Results:** The soft shoe setting had a medium effect ( $ES=0.66$ ) compared to the hard shoe setting. No medium or large effects were found in head acceleration or impact attenuation between shoes. Sand had the largest leg accelerations of 7.8 g's while the wooden bridge had the smallest (6.3 g's). Large effects were found in leg acceleration with sand and 3 different surfaces. Gravel had the largest head acceleration of 1.58 g's. Only medium effects were present between surfaces when comparing head accelerations. Sand had the highest impact attenuation of 83.8% while gravel had the smallest impact attenuation of 77.2%.

Discussion: Two of the softest surfaces (sand and grass) had the highest leg accelerations. This is believed to be due to changes made in kinematics while running on these two surfaces. Altering kinematics will change the effective mass of the body. The decrease in effective mass will increase leg accelerations even though the impact force may not have increased.

## CHAPTER I: INTRODUCTION

### Introduction

An estimated 30 million people in the United States run regularly (Austin, 2002). Of these 30 million active runners, approximately 48% will become injured during a one-year period (Walter et al., 1989). One factor that is believed to influence the potential for injury is the impact of the foot with the ground. This impact produces a peak in the ground reaction force that has a magnitude of 2-3 body weights and occurs approximately 25 ms after heel strike. During this impact the acceleration of the leg also peaks. This acceleration provides an alternative method for monitoring impacts during running. Accelerations measured at the head as well as the leg can provide information on how well the body attenuates the impact as it is transmitted through the skeletal system.

Advances in technology have made it possible for researchers to collect data outside the laboratory. Portable data loggers connected to accelerometers make it possible to collect running data during a typical run. Instead of collecting a single step per trial over a force platform, researchers can now collect every step over any surface they chose. This type of data collection has advantages and disadvantages. When collecting data outside of the laboratory, the ability to control some factors is lost. Running velocity is difficult to restrict outside of the laboratory, weather conditions are variable, and the runs are difficult for the researcher to monitor.

Although these disadvantages must be overcome, there are also advantages to this type of data collection. Thousands of impacts can be recorded during a short period of time. Instead of having ten impacts to analyze per condition, it's possible to look at hundreds of impacts per condition. Each subject is also running in their natural environment. The

limitations that are present with collecting data in the laboratory are gone allowing each subject to run as they would do on any other day.

### Statement of the Problem

1. very little data exist measuring leg accelerations on different surfaces
2. no data are available on how the running shoe interacts with different running surfaces

### Review of Literature

Overuse injuries are very common in running. Several factors have been associated with the development of running injuries. These include improper training methods, running surface, shoes, muscular imbalances and skeletal misalignments. The running shoe is thought to be capable of influencing two factors associated with running injuries:

1. higher impact force at ground contact
2. excessive pronation during stance

Running surfaces will absorb ground impacts differently depending on the cushioning and smoothness of the surface. Softer running surfaces such as sand, woodchips, and grass are thought to produce a lower impact than harder surfaces like asphalt and cement. The way a running shoe is constructed can increase or decrease the impact that is placed on the body. A running shoe with a high level of cushioning should have lower impacts than a low cushioning shoe. Pronation occurs when the foot rolls to the inside after the heel strikes the ground. If the pronation is excessive it may be a factor in some running injuries. Controlling the amount of impact the body must absorb and limiting the amount of pronation the foot will allow are keys in the designing of running shoes.

Impacts can be reduced by changing the cushioning properties of the shoe but the body does not always respond to changed cushioning in a predictable manner. De Koning and Nigg (1993), looked at how running barefoot, running in soft shoes, and running in hard shoes affected impact forces. Six subjects ran at 4.5 m/s in a laboratory over a force platform. It was found that leg stiffness was unchanged even though the cushioning was altered. The kinematics of subjects adapted to keep leg stiffness constant. Shorten and Mientjes (2003) found that medium and hard shoes actually reduced impacts. Soft shoes also reduced impacts from a control with minimal cushioning. Minor differences were reported using ground reaction forces. Bates and Stergiou (1996) found that soft midsoles reduced peak impact force by 1 N/kg compared to hard shoes. A similar study by Nigg and Liu (1999), found that more cushioned shoes increased the impacts slightly compared to less cushioned shoes. De Wit et al. (1995) also found similar results with less cushioned shoes producing lower impacts. One reason for these contrary results is that runners can adapt their running style to their perception of the midsole cushioning. When a runner feels this difference, they can alter the muscle activity or kinematics and this will affect leg stiffness.

New shoe designs have been developed over the past five to ten years. The Nike Shox® uses spring like devices on both the inside and outside of the sole to absorb impact and transmit that impact differently over the entire midsole. In a 2003 study by Aguinaldo and Mahar, these types of shoes were compared to a top brand conventional running shoe. The results of this study show that both kinds of shoes produced similar results in absorbing impact through the shoe. The Adidas One® running shoe allows the cushioning to be set at different levels with the use of a motorized cable within the heel portion of the midsole. Cushioning can also be adjusted by the shoe. A microprocessor is located on the bottom of



the shoe. This microprocessor takes up to 2000 readings a second to determine if the impacts are too hard or too soft. If the impacts are outside of an acceptable range, the motorized cable is adjusted by changing the tension.

Another possible way that impact can be absorbed is by using insoles in a shoe. The material used in the creation of the insole or midsole can affect the cushioning properties (Dixon et al., 2003). The two most common materials used in the construction of running shoes and insole cushions are ethyl vinyl acetate (EVA) foam and polyurethane (PU). Military subjects were asked to wear one of four insoles that was new at the time as well as an insole that was mechanically degraded by 40,000 impacts or approximately 100km while they performed their training. The results showed that no differences in impacts were present. However, two of the three insoles had lower loading rates than the standard issued insole provided to recruits.

The running surface could also have an affect on the prevalence of injuries. Surface stiffness and grade could alter the amount of impact the body absorbs. Downhill and uphill running have different effects on the impact forces (Gottschall & Kram, 2005). In a study looking at downhill running, the impact force saw a 54% increase from the flat surface. During uphill running the impact forces were reduced by 22%. This increase in impact force suggests that hill training, especially downhill running, increases the likelihood of an overuse injury occurring. Another study looked at the impact force of a 30 minute run on a treadmill with a grade of -12%. This study found that after 5 minutes of running, impact forces increased by 20% (Hardin & Hamill, 2002). This study supports the theory that downhill running will increase the impact force on the body.

Impact forces may also be affected by the stiffness of the surface. A study by Dixon, Collop, and Batt (2000) had six subjects run across a 15 meter long runway and force platform at 3.3 m/s. The runway varied from asphalt, acrylic, or a rubberized surface. 10 trials were used for each condition. It was found that the rubberized surface had the smallest impact force (1.58 BW) compared to asphalt (1.60 BW) and acrylic (1.62 BW) surfaces. The rubberized surface had a loading rate of 47.7 BW/sec while the asphalt surface had a loading rate of 51.4 BW/sec.

One concern when looking at the effect a surface may have on the impact forces is whether the runner is changing the kinematics of his or her body to adjust for the differing surface stiffness. Many studies support the theory that runners will adjust their leg stiffness to adapt to different surface stiffness levels. Hardin, Hamill, and Van den Bogert (2004) looked at the possible adaptations that footwear and surface have on running kinematics. They found that there was a decreased knee flexion angle at touchdown on harder surfaces. Changes in knee flexion have been suggested to be a possible indication of changes in leg stiffness. Another study by Hardin, Van Den Bogert & Hamill (2002) looked at the same two factors as well as running duration. This study involved two different experiments. The first experiment had subjects run with 3 different midsoles on 3 different surfaces. Runners adapted to the different midsole thickness and surface stiffness. In the second experiment subjects ran on a treadmill with a -12% grade for 30 minutes. The results of this study also showed an adaptation in kinematics over time. These adaptations show that runners will try to minimize the metabolic cost of running at the expense of impact force. Studies that look at leg stiffness on different surfaces support this theory. Runners changed their leg stiffness depending on the stiffness of the surface. The reasoning for changing leg stiffness is to

maintain the same running mechanics throughout. Leg stiffness changed by a 68% increase from the softest surface to the hardest surface (Ferris, Louie, & Farley, 1998). Ferris, Liang, and Farley (1999) looked at leg stiffness during the initial step on a new surface. The subjects ran on a rubberized track with four different combinations of surfaces. The four surfaces were: all soft surface, all hard surface, the first half soft and the second half hard, and the first half hard and the second half soft. Leg stiffness decreased by 29% from the last step on the soft surface to the first step on a hard surface. Leg stiffness increased by 17% from the last step on the hard surface to the first step on the soft surface. It is evident from these studies that changes in kinematics and leg stiffness play an important role in the interpretation of impact forces on different surfaces.

One other consideration to make involving different surfaces is how the mechanics of the stride changes when running on “off road” terrain (Creagh, Reilly, and Less, 1998). Three different terrains were used, a surfaced footpath, short grass, and long grass. The results showed that step length decreased as the terrain became rougher. Velocity also showed a decrease with rougher terrain. The terrain altered both the stride and velocity when running on rougher terrain.

Many factors can contribute to overuse running injuries. Decreasing the impact force on the body and limiting the amount of pronation the foot makes are keys to helping runners stay injury free. Different running surfaces and grade can alter the impact forces. Surface stiffness can alter the running kinematics that helps protect against high impact forces. These factors can influence injury potential.

### Thesis Organization

This thesis is organized into Introduction, Manuscript and General Conclusions Chapters. The manuscript is formatted according to Medicine and Science in Sports & Exercise specifications. References are included in the manuscript, with a full bibliography included at the end of the thesis. The informed consent documentation and the running questionnaire have been appended.

## **CHAPTER II: THE CHANGES MIDSOLE CUSHIONING AND RUNNING SURFACE HAVE ON IMPACTS**

A paper to be submitted to Medicine & Science in Sports & Exercise

Brett J. Sealand and Timothy R. Derrick

**Introduction:** One of the major factors related to overuse injuries in runners is impact force resulting from the runner hitting the ground at heel strike. This impact will increase and decrease based on the construction of the running shoe used as well as the type of surface being run on. The purpose of this research was to determine the effects that both midsole cushioning and surface stiffness have on this impact force.

**Methods:** Six recreation runners ran a 2.2 km course 3 times at a self selected pace. A variable cushioning running shoe (Adidas One®) was used and set in a low cushioning, high cushioning, or self adjusting cushioning mode for each run. The course consisted of the following surfaces: cement, asphalt, dirt, gravel, woodchips, sand, grass, and a suspension bridge.

**Results:** The soft shoe setting had a medium effect ( $ES=0.66$ ) compared to the hard shoe setting. Sand had the largest leg accelerations of 7.8 g's while wooden bridge had the smallest (6.3 g's). Gravel had the largest head acceleration of 1.58 g's. Only medium effects were present between surfaces when comparing head accelerations. Sand had the highest impact attenuation of 83.8% while gravel had the smallest impact attenuation of 77.2%.

**Discussion:** Two of the softest surfaces (sand and grass) had the highest leg accelerations. This is believed to be due to changes made in kinematics while running on these two surfaces. Altering kinematics will change the effective mass of the body. The

decrease in effective mass will increase leg accelerations even though the impact force may not have increased.

### Introduction

An estimated 30 million people in the United States run regularly (Austin, 2002). Of these 29 million active runners, approximately 48% will become injured every year (Walter et al., 1989). One factor that is believed to influence the potential for injury is the impact of the foot with the ground. This impact produces a peak in the ground reaction force that has a magnitude of 2-3 body weights and occurs approximately 25 ms after heel strike. During this impact the acceleration of the leg also peaks. This acceleration provides an alternative method for monitoring impacts during running. Accelerations measured at the head as well as the leg can provide information on how well the body attenuates the impact as it is transmitted through the skeletal system.

There are many factors that can play a role in the reduction of impacts and presumably the reduction of injuries in runners. Factors like speed, mileage, hills, surface hardness, shoe hardness, and anatomic misalignments can all play a role in the effects that impacts have on injury potential. Of these factors, midsole cushioning and running surface hardness do not substantially affect training methods and can be readily altered.

There has been much debate on the role midsole cushioning plays on impacts. Some studies have shown highly cushioned midsoles have a reduction in impact peaks when compared to lower cushioned midsoles (Bates and Stergiou, 1996). Other studies (Nigg and Liu, 1999 and De Wit et al. 1995) have shown that less cushioned midsoles have lower impact forces resulting from adjustments being made by the runner due to a harder shoe.

Runners will alter their kinematics or muscle activity to keep leg stiffness the same. This change in kinematics will reduce the impact force.

It is generally recognized that the amount of cushioning a shoe provides should be related to the surface a runner is running on. Harder surfaces require greater cushioning by the shoe. To this end, Adidas has developed a shoe that both senses and adjusts cushioning during a run to accommodate different cushioning requirements. This shoe also provides a unique protocol in which we can alter the cushioning of the shoe without removing it and without any other changes.

Very little data exist that have measured impacts while running on different surfaces. Dixon, Collop, and Batt (2000) found that a rubberized surface (1.58 BW) reduced impact force slightly when compared to asphalt (1.60 BW). Differences have been found using accelerometers. Lees and Jones (1994) found that the average peak deceleration on concrete was 26.5 m/s compared to 23.3 m/s on grass. Other factors such as surface smoothness and surface incline can play a role on impacts. Running uphill has shown to reduce impacts by 22% whereas downhill running can increase impact shock up to 54% (Gottschall & Kram, 2005).

The purpose of this study was to determine the effects of midsole cushioning and running surface stiffness on impacts and impact attenuation while running. As the surface stiffness increases we expect the midsole cushioning will play an increased role in reducing the impacts. Therefore, a soft midsole should have a larger effect on leg accelerations on surfaces such as asphalt and cement, than on surfaces like woodchips and sand. We also hypothesize that increased cushioning and more compliant surfaces will be associated with lesser peak leg accelerations.

## Methods

Six male recreational runners ( $25.5 \text{ years} \pm 2.3$ ) averaging  $1.78 \text{ m} \pm 0.046$  tall and with an average mass of  $75.6 \text{ kg} \pm 6.3$  participated in this study. Each subject ran at their preferred running velocity calculated during a  $\frac{1}{2}$  mile warm up. The average preferred velocity was  $3.54 \text{ m/s} \pm 0.27$ . Each subject completed 3 separate 1.5 mile runs in an Adidas One® running shoe size 9 or 11 (Adidas, Portland, Oregon). The Adidas One® running shoe allows the cushioning to be set at different levels with the use of a motorized cable within the heel portion of the midsole. 3 different midsole cushioning settings (soft, hard, & adjustable) were used. The condition order was balanced between subjects to minimize fatigue effects. Six different orders of presentation were possible and one was randomly chosen for each of the six subjects. A course consisting of cement, asphalt, dirt, grass, gravel, sand, woodchips, and a wooden suspension bridge was used. Each surface region was marked with two survey flags to indicate the start and end of each surface.

Accelerometers (Analog Devices, Norwood, MA) model ADXL 278 were attached to the distal antero-medial aspect of the leg and over the forehead. The two accelerometers were connected to a Crossbow data logger model AD2000 (Crossbow technology INC., San Jose, CA) that sampled data at 512 Hz. A customized trigger was also constructed and attached to the data logger. Each time the subject entered and exited a surface region they were instructed to push the trigger.

An Exeter Research Impact Tester (Exeter, NH) was used to determine the stiffness of the hard and soft shoe condition. An 8.5 kg mass was dropped onto the heel region of the running shoe while the shoe was in both the highest cushioned setting and lowest cushioned setting. A total of 35 impacts were completed on each shoe and the final 10 were averaged.



Surface regions were also impacted prior to the start of the study. A 4.5 kg Clegg hammer (Clegg Pty. Ltd., Wembley, Australia) was dropped 10 cm onto a hard shoe midsole. The impacts from 5 drops were measured on each surface at 5 separate temperatures (71°, 75°, 79°, 82°, and 90° F) throughout the day to estimate the effects of temperature on the impact values.

A Garmin Forerunner 301 GPS watch was used to calculate average running velocity during a ½ mile warm up. During data collection, speed threshold limits of  $\pm 5\%$  were set on the GPS watch. Speeds outside of this range resulted in an audible signal for the subject to modify running speed. The GPS watch was also used to calculate heart rate during each run.

Data analysis was performed using Matlab 7.0.1. A graphical indication when each trigger push occurred was cross-referenced with when each trigger push should have occurred based on the average time of each condition. This graph was used to check against any improper or missing trigger points. Peak leg, peak head and impact attenuation were calculated from the two accelerometers. Impact attenuation was calculated as  $(1 - (\text{peak head} / \text{peak leg})) * 100$ . Cohen's D formula was calculated to determine effect sizes between shoes and surfaces.

## Results

Average peak accelerations of each surface showed no major changes with a change in temperature (Table 1). Since peak g values were relatively stable within this temperature range the average values were used to represent the surface hardness. All subjects ran at a temperature within this range. The woodchip surface had the smallest peak acceleration of

8.9 g's indicating it was the softest surface while cement had the highest peak acceleration of 28.6 g's and thus was the hardest surface.

Table 1. Mechanical surface impacts at 5 different temperatures (impacts measured in g's).

Temperature	71°F	75 °F	79 °F	82 °F	90 °F	Mean
1. Woodchips	10.6	8.4	8.2	9.4	8.0	8.9
2. Sand	9.6	11.4	8.6	10.4	13.6	10.7
3. Grass	15.0	15.2	14.4	14.2	15.2	14.8
4. Wood Bridge	25.4	24.0	25.8	25.2	24.0	24.9
5. Gravel	26.0	26.6	26.4	25.8	22.8	25.5
6. Dirt	27.0	26.4	24.6	25.6	27.2	26.2
7. Asphalt	29.6	25.8	27.0	26.6	25.4	26.9
8. Cement	31.2	27.8	29.0	28.0	27.0	28.6

### Shoes

A compilation of 15 commercially available running shoes had an average peak acceleration of 9.7 g's with a range of 7.2-11.2 g's using the mechanical impact test. The Adidas One® running shoe had an average impact value of 10.9 g's on the soft setting and 13.7 g's on the hard setting. Thus, the soft setting corresponded with a typical running midsole cushioning while the hard setting was well above the typical range.

An average of 957 right leg impacts were analyzed for each run. The hard midsole had an average peak leg acceleration of  $7.2 \text{ g's} \pm 1.01$  and the soft midsole had an average peak acceleration of  $6.6 \text{ g's} \pm 0.78$ . A medium effect was present for peak leg acceleration between the soft and hard shoe condition ( $ES=0.66$ ). When the subjects ran with the adjustable setting the average peak leg acceleration was  $7.0 \text{ g's} \pm 1.15$ . Because the automatic adjustment may not have been immediate upon entering a new surface we will not report statistics for this condition.

No medium or large effects were seen between midsole hardnesses for head acceleration or impact attenuation. The soft midsole had an average peak head acceleration of  $1.32 \text{ g's} \pm 0.33$  while the hard and adjustable midsole conditions had peak values of  $1.46 \text{ g's} \pm 0.48$  and  $1.48 \text{ g's} \pm 0.57$  respectively. The effect size between the soft and hard midsole conditions for head acceleration was 0.35. The soft midsole also exhibited the highest impact attenuation value of  $80.0\% \pm 5.1$ . The hard shoe had an average impact attenuation value of  $79.7\% \pm 4.8$ , while the adjustable shoe condition had a impact attenuation of  $79.0\% \pm 5.6$ .

The only surface that did not have a medium or large effect between the hard and soft midsole cushioning was the woodchip surface. Medium effects were seen on sand, grass, wooden bridge, gravel, dirt, and asphalt. Cement had a large effect with a change in midsole cushioning ( $ES= 0.91$ ). In general, the effect sizes increased as the surface became harder.

Table 2. Midsole cushioning effects on peak leg acceleration for different surfaces.

Surface (hardness in g's)	Hard Midsole (g's)	Soft Midsole (g's)	Effect Size
1. Woodchips (8.9)	6.8	6.4	0.34
2. Sand (10.7)	8.3	7.4	0.55
3. Grass (14.8)	7.8	7.1	0.50
4. Wood Bridge (24.9)	6.6	6.0	0.55
5. Gravel (25.5)	7.1	6.3	0.59
6. Dirt (26.2)	7.0	6.4	0.54
7. Asphalt (26.9)	6.9	6.2	0.79
8. Cement (28.6)	7.4	6.5	0.91
Mean	7.2	6.6	0.67

No medium or large effects were seen in head acceleration on any surface when changing midsole cushioning. Peak head acceleration in the soft midsole ranged from the wooden bridge with a value of  $1.12 \text{ g's} \pm 0.26$  to gravel with a value of  $1.43 \text{ g's} \pm 0.45$ . The wooden bridge also had the smallest peak head acceleration of  $1.21 \text{ g's} \pm 0.35$  while gravel had the highest peak head acceleration of  $1.61 \text{ g's} \pm 0.58$ .

Table 3. Midsole cushioning effects on peak head acceleration for different surfaces.

Surface (hardness in g's)	Hard Midsole (g's)	Soft Midsole (g's)	Effect Size
1. Woodchips (8.9)	1.38	1.27	0.29
2. Sand (10.7)	1.34	1.17	0.46
3. Grass (14.8)	1.61	1.40	0.40
4. Wood Bridge (24.9)	1.21	1.12	0.31
5. Gravel (25.5)	1.61	1.43	0.36
6. Dirt (26.2)	1.50	1.35	0.30
7. Asphalt (26.9)	1.47	1.30	0.37
8. Cement (28.6)	1.52	1.36	0.37
Mean	1.46	1.32	0.35

No midsole cushioning effects were present in impact attenuation on any surface.

The impact attenuation values in both midsoles ranged from of 83.8% in sand to 77.2% in gravel.

Table 4. Midsole cushioning effects on impact attenuation for different surfaces.

Surface (hardness in g's)	Hard Midsole (g's)	Soft Midsole (g's)	Effect Size
1. Woodchips (8.9)	79.5	79.9	0.07
2. Sand (10.7)	83.8	83.8	0.00
3. Grass (14.8)	79.7	79.8	0.02
4. Wood Bridge (24.9)	81.2	81.0	0.06
5. Gravel (25.5)	77.2	77.2	0.01
6. Dirt (26.2)	78.7	78.6	0.02
7. Asphalt (26.9)	79.2	78.5	0.12
8. Cement (28.6)	79.5	78.7	0.14
Mean	79.9	80.0	0.06

### Surfaces

The smallest peak leg acceleration was on the wood bridge (6.3 g's) while the largest value was on the sand (7.4 g's). Woodchips, gravel, dirt, and asphalt all had medium effects on the peak leg acceleration when compared with grass (Table 4). Sand and the wooden bridge also had medium effects compared to the cement. Large effects were present when comparing sand to woodchips, the wooden bridge, gravel, dirt, and asphalt. A large effect was also present between the wooden bridge and grass surface.

Table 5. Surface effects on leg acceleration.

Surface (hardness in g's)	Mean (g's)	Medium Effects with Surfaces:	Large Effects with Surfaces:
1. Woodchips (8.9)	6.6	3	2
2. Sand (10.7)	7.9	8	1,4,5,6,7
3. Grass (14.8)	7.5	1,5,6,7	4
4. Wood Bridge (24.9)	6.3	8	2,3
5. Gravel (25.5)	6.7	3	2
6. Dirt (26.2)	6.7	3	2
7. Asphalt (26.9)	6.6	3	2
8. Cement (28.6)	6.9	2,4	
Mean	6.9		

The smallest peak head acceleration was on the wooden bridge (1.21 g's) while the largest value was on the gravel surface (1.58 g's). A large effect existed for peak head acceleration when comparing gravel and grass to the wooden bridge. Medium effects existed when the wooden bridge was compared to asphalt, dirt, and cement. Sand, which had a peak g value of 1.25, also had a medium effect when compared to grass and gravel.

Table 6. Surface effects on head acceleration.

Surface (hardness in g's)	Mean (g's)	Medium Effects with Surfaces:	Large Effects with Surfaces:
1. Woodchips (8.9)	1.33		
2. Sand (10.7)	1.26	3,5	
3. Grass (14.8)	1.53	2	4
4. Wood Bridge (24.9)	1.21	6,7,8	3,5
5. Gravel (25.5)	1.58	2	4
6. Dirt (26.2)	1.46	4	
7. Asphalt (26.9)	1.41	4	
8. Cement (28.6)	1.49	4	
Mean	1.41		

Sand had the highest impact attenuation value of  $83.8\% \pm 4.48$  while gravel had the lowest impact attenuation value of  $77.2\% \pm 6.65$ . Sand had a large effect when compared to woodchips, grass, gravel, dirt, cement, and asphalt. Sand also had a medium effect when compared with the wood bridge. The wood bridge had a medium effect when compared to gravel.

Table 7. Surface effects on impact attenuation.

Surface (hardness in g's)	Mean (%)	Medium Effects with Surfaces:	Large Effects with Surfaces:
1. Woodchips (8.9)	79.68		2
2. Sand (10.7)	83.83	4	7,8,1,3,5,6
3. Grass (14.8)	79.71		2
4. Wood Bridge (24.9)	81.07	2,5	
5. Gravel (25.5)	77.19	4	2
6. Dirt (26.2)	78.62		2
7. Asphalt (26.9)	78.87		2
8. Cement (28.6)	79.13		2
Mean	79.57		

The woodchip surface had the smallest change between shoe conditions with a difference of 0.4 g's. The sand and the cement had the largest change from soft cushioning to hard cushioning (0.9 g's).

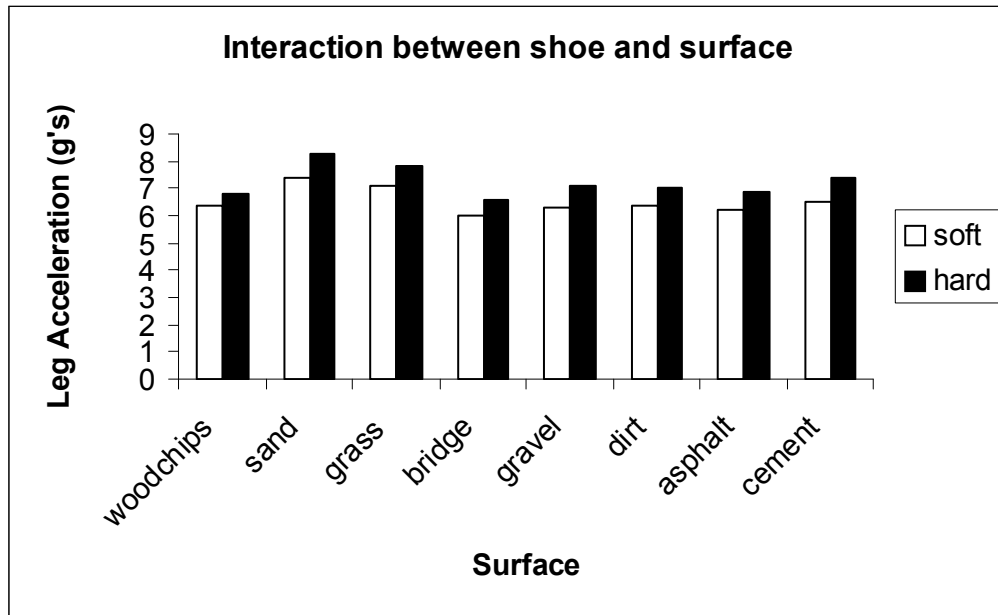


Figure 1. Peak leg acceleration for each shoe condition on eight running surfaces.

### Discussion

The purpose of this study was to determine what role midsole cushioning and running surface stiffness play on impacts and impact attenuation while running. Our first hypothesis was that midsole cushioning would play an increasingly important role on harder surfaces. Table 2 indicates a relationship between the surface hardness and the size of the effect on peak leg acceleration. The correlation between surface hardness and effect size was 0.73, indicating that harder surfaces and a greater cushioning effect. We also hypothesized that increased cushioning and softer surfaces would be associated with lesser peak leg accelerations. The softer midsole reduced the average peak leg acceleration from 7.2 g's to 6.6 g's (Table 3) and there was a correlation of -0.26 between the surface hardness and the



average peak leg acceleration (Table 4). This correlation indicates that harder surface are associated with greater peak leg accelerations but this is not a strong relationship.

Overall, there was a 9% decrease in leg acceleration from the hard shoe condition to the soft shoe condition. During mechanical impact testing, a 23% difference was found. It is possible that the runners could sense the altered midsole cushioning and adjusted kinematics accordingly. However, these adaptations did not fully compensate for the change in midsole cushioning. Sand had the highest peak leg accelerations yet it was the second softest surface based on our surface impact testing. We expected that the peak leg acceleration would be one of the lowest during the sand running. The high accelerations are probably due to a change in kinematics that occurs during running on the sand (Pinnington et al., 2005). It was shown that running in sand at 11 km/hr would result in an average knee flexion at impact of  $41.5^{\circ}$  while knee flexion at impact was only  $6.1^{\circ}$  while running at the same speed on a carpeted wooden surface. In general, running on a more compliant surface will cause someone to run with more knee flexion compared to a harder, less compliant surface (McMahon, 1979). It might be thought that increased knee flexion would reduce the impact even further but flexing the knee at ground contact reduces the mass accelerated by the impact. A smaller mass is easier to accelerate and thus peak accelerations can increase with increased knee flexion at contact (Derrick, 2004).

Derrick also showed there is an increase in knee flexion when running on an irregular surface ( $12.5^{\circ}$  on a smooth surface vs.  $14.0^{\circ}$  on an irregular surface). An increase in peak leg acceleration of 0.7 g's was also present (Derrick, 2004) during the irregular surface running even though there was no change in shoe or surface hardness. Due to the rough terrain that exists while running on grass and sand, there was probably a change in kinematics due to

surface irregularities. Subjects may have been uncomfortable running on rough terrain and they could have altered the way they ran in order to ensure that they would not sprain an ankle or fall. The second highest leg acceleration was the grass. This was the third softest surface when mechanically testing the surfaces. This increase in acceleration could have been due to the same change in kinematics as running on the sand. The grass had the second highest impact attenuation value behind sand. It may be possible for other softer surfaces such as sand and grass to lower leg accelerations compared to harder surfaces like asphalt and cement if no kinematic adjustments are being made to compensation for surface irregularities. The other surfaces showed higher peak leg acceleration values as the surfaces became harder.

Five of the eight surfaces had impact attenuation values between from 78.68% - 79.13%. The two surfaces with higher attenuations were sand and grass. This could be due to the possible change in kinematics mentioned above. The one surface with lower attenuation than the rest of the surfaces was gravel.

Given the dependence of peak leg acceleration values on kinematics, perhaps peak head acceleration values would offer a better indicator of impact loading on the body. Both midsole cushioning and surface have an effect on the impacts experienced by the body. The running shoe reduced head impacts by 10% and surfaces reduced head impact by 18%.

## References

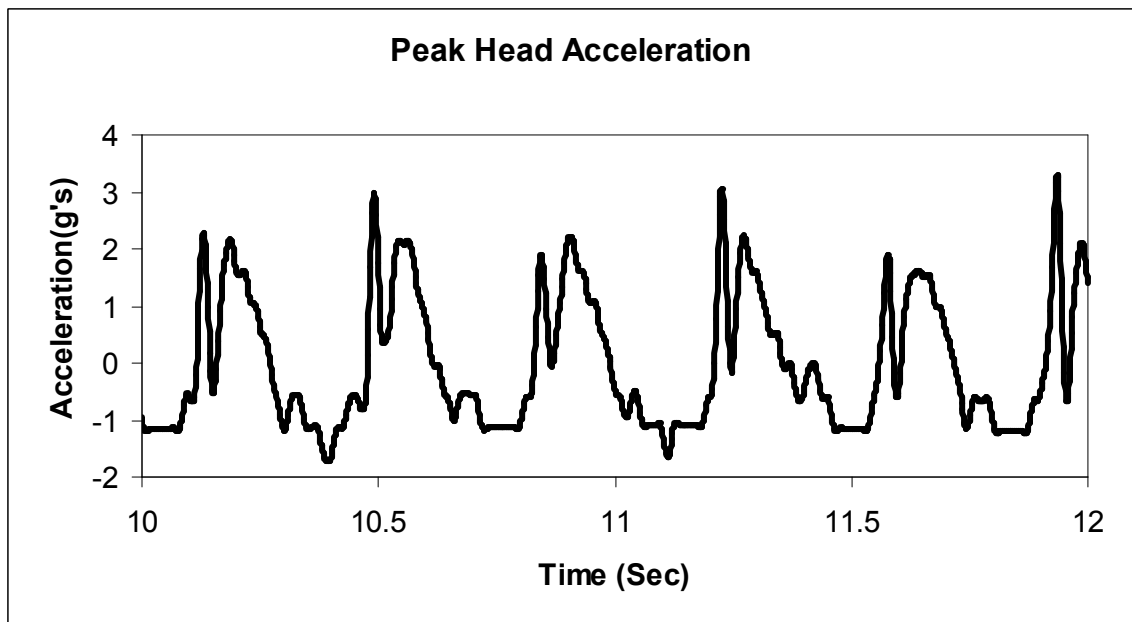
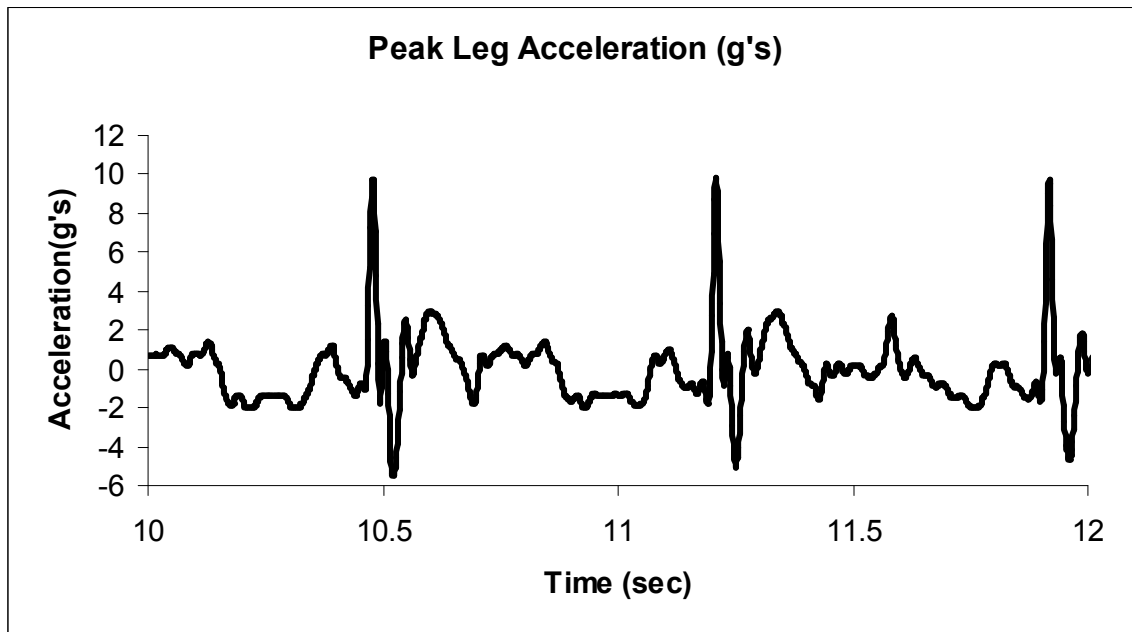
- Austin, W. Chiropractic health for recreational runners. *The Journal of the American Chiropractic Association*. 39:32-37, 2002.
- Bates, B., and N. Stergiou. Performance accommodation to midsole hardness during running. *Journal of Human Movement Studies*. 31:189-210, 1996.
- De Wit, B., D. De Clercq, and M. Lenoir. The effect of varying midsole hardness on impact forces and foot motion during foot contact in running. *Journal of Applied Biomechanics*. 11:395-406, 1995.
- Derrick, T. The effects of knee contact angle on impact forces and accelerations. *Medicine and Science in Sports and Exercise*. 36:832-837, 2004
- Dixon, S., A. Collop, and M. Batt. Surface effects on ground reaction forces and lower extremity kinematics in running. *Medicine & Science in Sports & Exercise*. 32:1919-1926, 2000.
- Gottschall, J., and R. Kram. Ground reaction forces during downhill and uphill running. *Journal of Biomechanics*. 38:445-452, 2005
- Lees, A., and H. Jones. The effect of shoe type and surface type on peak shank deceleration. *Journal of Sports Sciences*. 12:173, 1994.
- McMahon, T., and P. Greene. The influence of track compliance on running. *Journal of Biomechanics*. 12:893-904, 1979.
- Nigg, B., and W. Liu. The effect of muscle stiffness and damping on simulated impact force peaks during running. *Journal of Biomechanics* 32:849-856, 1999.
- Pinnington, H., D. Lloyd, T. Beiser, and B. Dawson. Kinematic and electromyographic analysis of submaximal running on a firm surface compared with soft, dry sand. *European Journal of Applied Physiology*. 94:242-253, 2005.
- Walter, S., L. Hart, J. McIntosh, and R. Sutton. The Ontario cohort study of running-related injuries. *Archives of Internal Medicine*. 149:2561-2564, 1989.

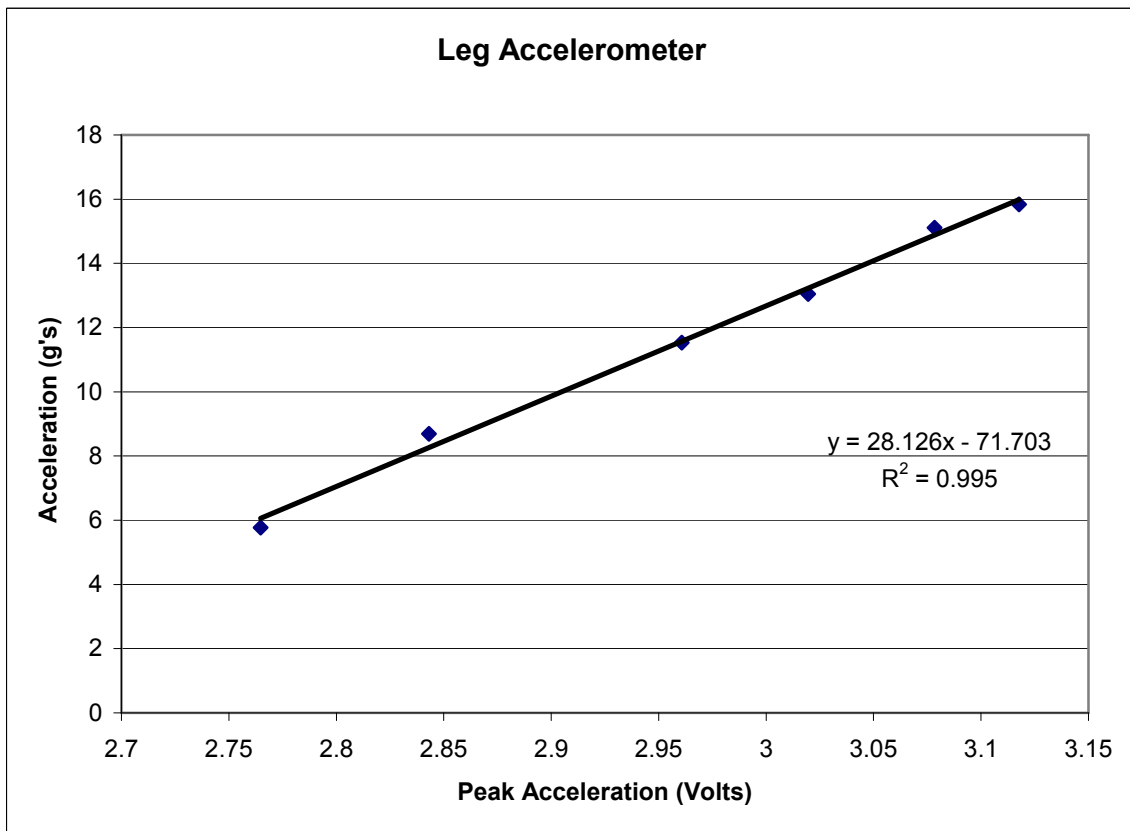
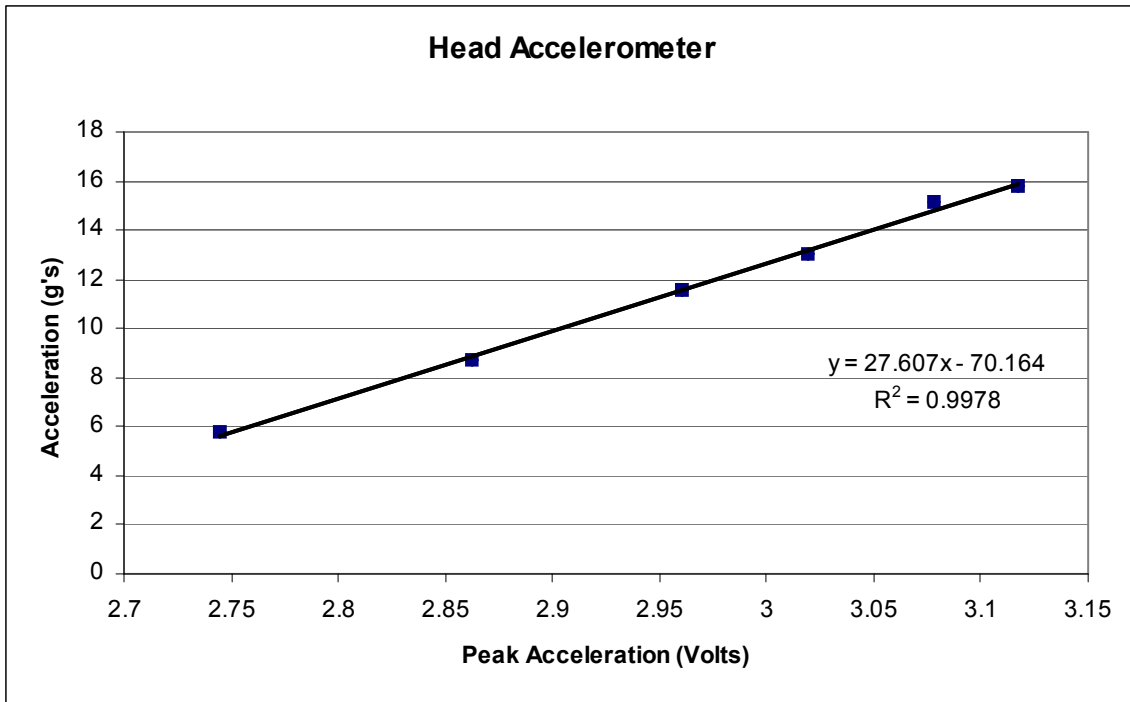
### CHAPTER III: GENERAL CONCLUSIONS

Midsole cushioning seems to be more influential on leg acceleration than does surface hardness. On all surfaces, the soft shoe setting had lower peak leg accelerations than the hard shoe setting. This suggests that no matter where running takes place midsole cushioning plays a role on impact acceleration at the leg. The correlation between surface hardness and peak leg acceleration was relatively low (-0.26). The peak impact acceleration at the leg is likely dependant on the kinematics being used on each individual surface.

Impact attenuation may not be affected by midsole cushioning. No differences were present between any of the three shoe settings. Impact attenuation could also be independent of surface hardness, but will change based on kinematic adjustments being made due to surface irregularities.

An interaction for leg acceleration was present for midsole cushioning and surface hardness. A correlation of 0.73 was found when comparing the effect sizes. The role the shoe plays on each surface is highly variable. The woodchips surface had the smallest effect size of 0.34. Cement had the largest effect size of 0.91. These two surfaces were also the softest and the hardest surfaces from mechanical testing.

**APPENDIX A: ACCELERATION DATA**



## **APPENDIX B: INFORMED CONSENT**

### INFORMED CONSENT DOCUMENT

Title of Study: Surface Effects on shock attenuation and rearfoot motion in runners wearing a shoe with different levels of cushioning

Investigators: Brett Sealine BA, Tim Derrick PhD, Abby Jorgenson BS, Morgan Brubaker, Brian Salton, Allison Haberkorn

This is a research study. Please take your time in deciding if you would like to participate. Please feel free to ask questions at any time.

### INTRODUCTION

The purpose of this study is to find whether there is a difference in shock attenuation and rearfoot motion in runners while running on a variety of everyday running surfaces in shoes with different cushioning levels. This information can be beneficial in determining the likelihood of developing a running injury. You are being invited to participate in this study because you are a recreational runner who runs more than 10 miles a week.

### DESCRIPTION OF PROCEDURES

If you agree to participate in this study, your participation will last for 1 day and will involve 1 visit to the health and human performance department lasting approximately 2 hours. During the study you may expect the following study procedures to be followed. You will be asked to complete a survey about your exercise history. Then, An accelerometer used to measure shock on the body will be attached to the leg and another accelerometer will be strapped to the forehead. Each accelerometer is approximately 1 square inch big. An eletrogoniometer used to measure joint angels may also be attached to your lower leg. Both the accelerometers and electrogoniometer will be connected to a data logger which will be held in a fannypack that is wrapped around your waist. Each subject will also have 2 GPS watches strapped to their wrists with a heart rate monitor placed around their chest. You will be asked to run a 1/2 mile warm up out to Brookside Park. Out at the park, you will run 100 meters in order to calculate the correct running pace for the duration of the study. This pace will be calculated using the information gathered from the GPS watch. Then you will run 3- 1.5 mile runs out at Brookside Park. Each run will be done wearing an Adidas One® running shoe provided with three different cushioning levels. The three diferent cushioning levels are: the softest the shoe can be set to, the hardest the shoe can be set to, and a setting that will allow to make adjustments based on what surfaces are being run on. You will be asked to follow a pre-determined course marked out containing cement, asphalt, grass, dirt, sand, and woodchips. The course will also include hills of varying grades.

### RISKS

While participating in this study you may experience the following risks: During the data collection you will be running up to 5 miles. Some cardiovascular and/or muscle fatigue is possible. We are recruiting recreational runners (>10 miles a week) for this study to try to eliminate this discomfort. Muscle soreness could occur. This soreness should be gone in 2-3 days. There are no invasive procedures used in this study.

## BENEFITS

If you decide to participate in this study there may be no direct benefit to you. Participation in this study will allow you to be physically active which could be beneficial to you. It is hoped that the information gained in this study will benefit society by further understanding the combination of how the running surface and running shoe can affect the occurrence of injury.

## COSTS AND COMPENSATION

You will not have any costs from participating in this study. You will not be compensated for participating in this study

## PARTICIPANT RIGHTS

Your participation in this study is completely voluntary and you may refuse to participate or leave the study at any time. If you decide to not participate in the study or leave the study early, it will not result in any penalty or loss of benefits to which you are otherwise entitled.

## RESEARCH INJURY

Emergency treatment of any injuries that may occur as a direct result of participation in this research is available at the Iowa State University Thomas B. Thielen Student Health Center, and/or referred to Mary Greeley Medical Center or another physician or medical facility at the location of the research activity. Compensation for any injuries will be paid if it is determined under the Iowa Tort Claims Act, Chapter 669 Iowa Code. Claims for compensation should be submitted on approved forms to the State Appeals Board and are available from the Iowa State University Office of Risk Management and Insurance

## CONFIDENTIALITY

Records identifying participants will be kept confidential to the extent permitted by applicable laws and regulations and will not be made publicly available. However, federal government regulatory agencies and the Institutional Review Board (a committee that reviews and approves human subject research studies) may inspect and/or copy your records for quality assurance and data analysis. These records may contain private information.



To ensure confidentiality to the extent permitted by law, the following measures will be taken: your information will only be identified using your initials. All paperwork will be kept in Dr. Derrick's office. If the results are published, your identity will remain confidential.

## QUESTIONS OR PROBLEMS

You are encouraged to ask questions at any time during this study.

- For further information about the study contact Tim Derrick (515) 294-8438.
- If you have any questions about the rights of research subjects or research-related injury, please contact Ginny Austin Eason, IRB Administrator, (515) 294-4566, [austingr@iastate.edu](mailto:austingr@iastate.edu), or Diane Ament, Research Compliance Officer (515) 294-3115, [dament@iastate.edu](mailto:dament@iastate.edu).

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## SUBJECT SIGNATURE

Your signature indicates that you voluntarily agree to participate in this study, that the study has been explained to you, that you have been given the time to read the document and that your questions have been satisfactorily answered. You will receive a copy of the signed and dated written informed consent prior to your participation in the study.

Subject's Name (printed) \_\_\_\_\_

\_\_\_\_\_  
(Subject's Signature)

\_\_\_\_\_  
(Date)

**[Include the Parent/Guardian/Legally Authorized Representative signature line only if applicable to your study.]**

\_\_\_\_\_  
(Signature of Parent/Guardian or  
Legally Authorized Representative)

\_\_\_\_\_  
(Date)

## INVESTIGATOR STATEMENT

I certify that the participant has been given adequate time to read and learn about the study and all of their questions have been answered. It is my opinion that the participant understands the purpose, risks, benefits and the procedures that will be followed in this study and has voluntarily agreed to participate.

---

(Signature of Person Obtaining  
Informed Consent)

---

(Date)

**APPENDIX C: RUNNING HISTORY**

## Running Questionnaire

Subject ID: \_\_\_\_\_

Date: \_\_\_\_\_

**Subject Information**

Height: (cm) \_\_\_\_\_

Mass (kg) \_\_\_\_\_

Age: (years) \_\_\_\_\_

Gender: \_\_\_\_\_

**Running Information**

Mileage per week: \_\_\_\_\_

Months at current mileage: \_\_\_\_\_

Easy run pace: \_\_\_\_\_

Do you have any current running injuries? If yes, please explain.

\_\_\_\_\_  
\_\_\_\_\_

Are there any reasons why you cannot complete this study? If yes please explain.

\_\_\_\_\_  
\_\_\_\_\_

## BIBLIOGRAPHY

- Aguinaldo, A., and A. Mahar. Impact loading in running shoes with cushioning column systems. *Journal of Applied Biomechanics*. 19:353-360, 2003.
- Austin, W. Chiropractic health for recreational runners. *The Journal of the American Chiropractic Association*. 39:32-37, 2002.
- Bates, B., and N. Stergiou. Performance accommodation to midsole hardness during running. *Journal of Human Movement Studies*. 31:189-210, 1996.
- Creagh, U., T. Reilly, and A. Less. Kinematics of running on “off-road” terrain. *Ergonomics*. 4:1029-1033, 1998.
- De Koning, J., and B. Nigg. Kinematic factors affecting initial peak vertical ground reaction forces in running. *Proceedings of the XIV<sup>th</sup> International Congress of Biomechanics*, Paris, France, 316-317, 1993.
- De Wit, B., D. De Clercq, and M. Lenoir. The effect of varying midsole hardness on impact forces and foot motion during foot contact in running. *Journal of Applied Biomechanics*. 11:395-406, 1995.
- Derrick, T. The effects of knee contact angle on impact forces and accelerations. *Medicine and Science in Sports and Exercise*. 36:832-837, 2004
- Dixon, S., C. Waterworth, C. Smith, and C. House. Biomechanical analysis of running in military boots with new and degraded insoles. *Medicine & Science in Sports & Exercise*. 35:472-479, 2003.
- Dixon, S., A. Collop, and M. Batt. Surface effects on ground reaction forces and lower extremity kinematics in running. *Medicine & Science in Sports & Exercise*. 32:1919-1926, 2000.
- Ferris, D., K. Liang, and C. Farley. Runners adjust leg stiffness for their first step on a new running surface. *Journal of Biomechanics*. 32:787-794, 1999.
- Ferris, D., M. Louie, and C. Farley. Running in the real world: adjusting leg stiffness for different surfaces. *Proceedings: Biological Sciences*. 265:989-994, 1998
- Gottschall, J., and R. Kram. Ground reaction forces during downhill and uphill running. *Journal of Biomechanics*. 38:445-452, 2005
- Hardin, E., A. Van Den Bogert, and J. Hamill. Kinematic adaptations during running: effects of footwear, surface, and duration. *Medicine & Science in Sports and Exercise*. 36:838-844, 2004.

- Hardin, E., and J. Hamill. The influence of midsole cushioning on mechanical and hematological responses during a prolonged downhill run. *Research Quarterly for Exercise and Sport*. 73:125-134, 2002.
- Hreljac, A., R. Marshall, and P. Hume. Evaluation of lower extremity overuse injury potential in runners. *Medicine and Science in Sports and Exercise*. 32:1635-1641, 2000.
- Lees, A., and H. Jones. The effect of shoe type and surface type on peak shank deceleration. *Journal of Sports Sciences*. 12:173, 1994.
- McMahon, T., and P. Greene. The influence of track compliance on running. *Journal of Biomechanics*. 12:893-904, 1979.
- Nigg, B., and W. Liu. The effect of muscle stiffness and damping on simulated impact force peaks during running. *Journal of Biomechanics* 32:849-856, 1999.
- Pinnington, H., D. Lloyd, T. Beiser, and B. Dawson. Kinematic and electromyographic analysis of submaximal running on a firm surface compared with soft, dry sand. *European Journal of Applied Physiology*. 94:242-253, 2005.
- Shorten, M., and Mientjes, M. The effects of shoe cushioning on impact force during running. *Proceedings of the 6<sup>th</sup> Symposium on Footwear Biomechanics*. Queenstown, New Zealand, 2003.
- Walter, S., L. Hart, J. McIntosh, and R. Sutton. The Ontario cohort study of running-related injuries. *Archives of Internal Medicine*. 149:2561-2564, 1989.