The pitfalls of heals and extra weight

Introduction

In today's fashion there are many features which, while seeming very appealing, have many hidden hazards. One such aspect involves shoes with high heels.
High heels are at the height of fashion in the opinion of many women and have become a part of formality and superiority as well as image. However, shoes with high heels are found to be very uncomfortable and are a cause of more frequent falls and many injuries. They also affect posture and may cause several foot injuries and disorders such as sesamoiditis if worn on a regular basis. These hazards are caused by a higher portion of the body weight being placed on the balls of the feet whereas flat shoes spread the weight more evenly around the foot. This causes tiredness of feet and also may affect the bones of feet, causing minor injuries in the bones of the balls of the feet (i.e. metatarsals).

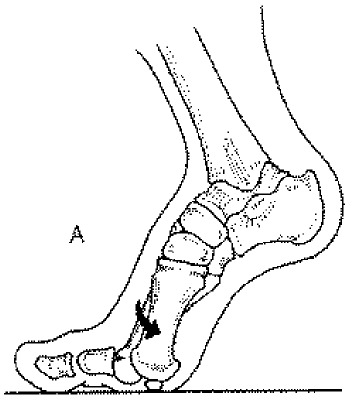

Figure 1 – Foot in position of wearing high heels, metatarsal pointed out

This experiment investigates the different types of heels of different heights and examines how the different heel heights will vary the stress and strain places on the bones of the feet. This will demonstrate the impact of wearing high heels compared to wearing flat shoes.

Theory

When people walk, forces on the bones of the feet, are evenly distributed over the bones of the whole foot and leg. When wearing heels, more weight is placed on the forefoot (i.e. metatarsals).The first metatarsal bone is about a quarter the length of the

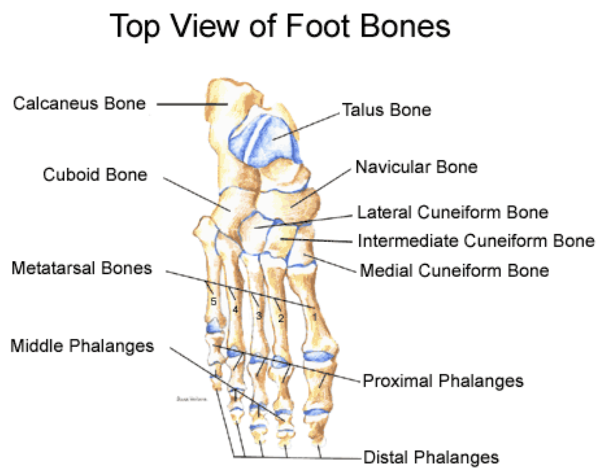

Figure 2– Top view of foot bones

foot, so in the case of the control, it is 4cm long and about 1.4 cm thick. The metatarsals can take a large amount of stress (eg when landing from a jump).

Bones are linearly elastic material, so Hooke's law can be applied to it. Some can measure stress in the bones using the formula,

$\sigma = F/A$

And the same for strain

$\varepsilon = \Delta L / L_o$

By applying Hooke's law for a linearly elastic material, in this case bones,

$F/A = Y \Delta L / L$, where Y is the Young's modulus.

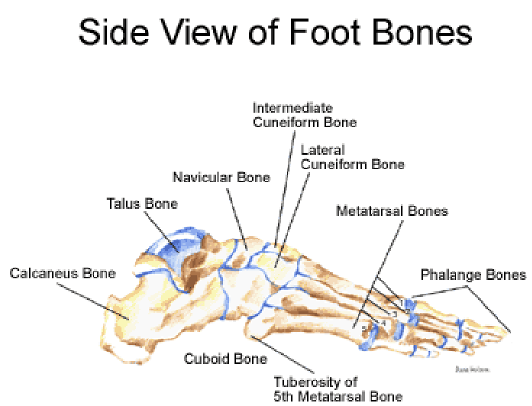

Figure 3 – Side view of foot bones

This measures the amount in which the bone has been shortened, ΔL, when wearing different types of shoes with different heights that will vary the weight force, F on the foot bones.

Materials and methods

Tests were performed on a selected range of shoes with differing heel heights. These heights included:

- 0.5cm
- 2cm
- 5cm
- 7.5cm

Measurements were taken by using a force plate, Pico scope and a computer.

The force plate was connected to the Pico scope. The Pico scope was then connected to the computer in order to measure the voltage corresponding to the weight force applied to the force plate. These measurements were recorded using the Pico scope software individually and the reading was taken by the highest peak produced. Such an example of a measurement of the uppermost peak is shown in figure 4.

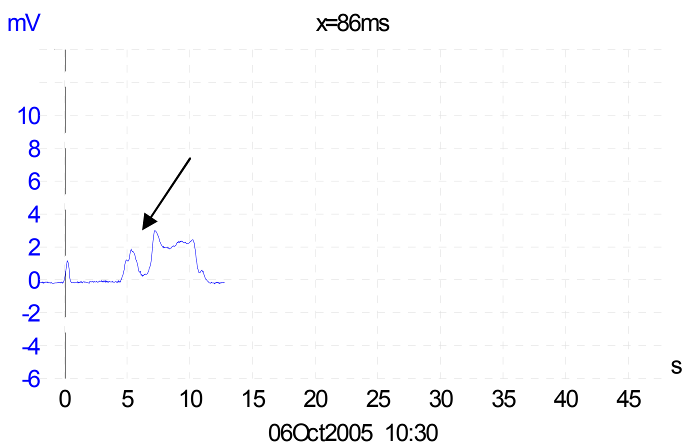

Figure 4 – Max peak from a Pico scope measurement

In order to translate voltage to force, a standard curve was created, by measuring the voltage produced by known weights on the force plate. Several varying weights, comparable to the test weight, were used to produce a more accurate standard curve of weight force versus voltage. A polynomial trendline was fitted and the equation of this line was used to translate the voltage of the experimental mass into force.

Mass (Kg)	Voltage (mV)	Weight (N)
101.5	10	994.7
48	3	470.4
70	4	686
52	3.5	509.6
46	3	450.8
90	6	882
12	0.6	117.6

Table1- Data for standard curve

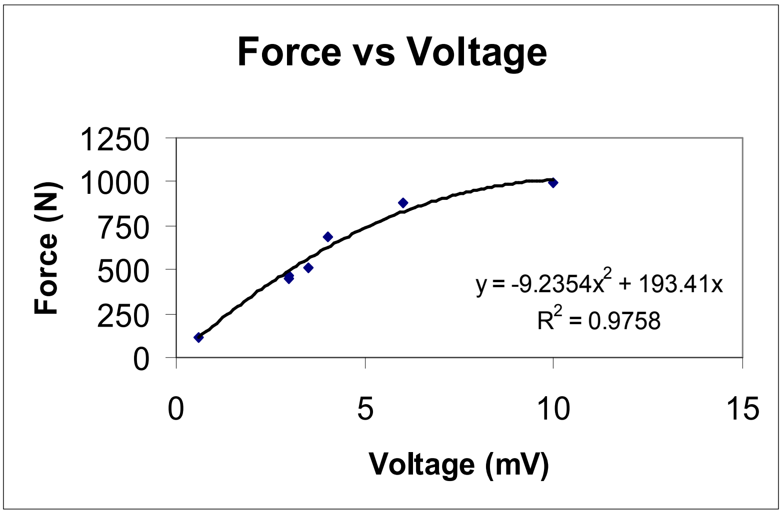

Figure 5 – Graph of force vs. voltage

One test individual was selected to perform the experimental procedures so that the test weight remained constant. The test individual stood with the balls of the feet on the force plate and the heels on the level platform next to the force plate. This allowed only the force on the balls of the feet to be measured. Once the voltages corresponding to each heel height were found and translated to force, the stress and strain on the metatarsal bone could be determined using the following formula.

For stress,

$\sigma = F/A$

For strain,

$\varepsilon = \Delta L / L_o$

The figures below, figures 6, 7, 8 and 9 shows the various different heel heights of shoes which were used in this particular experiment.

Figure 6 – Flat shoes

Figure 7 – shoes with heel height of 2cm

Figure 8 – shoes with heel height of 5cm

Figure 9 – shoes with heel height of 7.5cm

Results

The force plate was used in these tests as shown in Table 2 to show the amount of voltage attained at different heel heights. The uncertainties were also recorded. Table 3 shows the amount of force recorded by each of the different heel heights. This was obtained by taking the equation ($y = -9.2354x^2 + 193.41x$), from figure 1, and substituting the amount of voltage as x. The results for Table 1 and 2 have been graphed, as shown in figures 6 and 7 consecutively. Figure 7 shows a linear relationship of the heel height against the voltage measured.

Heel Height (cm)	**mV (Max Peak)**
Flat shoes (0.5)	1 ± 0.02
2	2 ± 0.02
5	3.8 ± 0.02
7.5	5 ± 0.02
Full weight	6 ± 0.02

Table 2 – The voltage recorded at different heel heights

Heel Height (cm)	**Force (N)**
Flat shoes (0.5)	1.8×10^2
2	3.5×10^2
5	6.0×10^2
7.5	7.4×10^2

Table 3 – The Force recorded at different heel heights

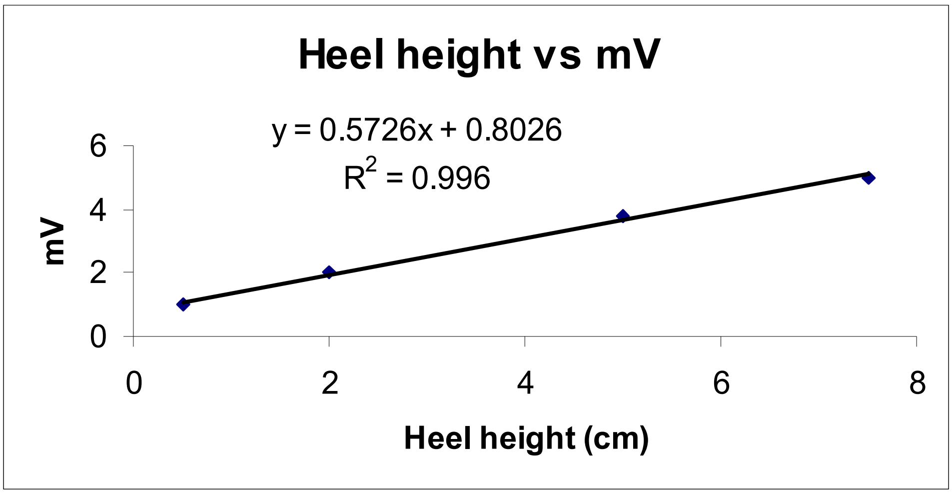

Figure 10– Graph of Voltage vs. heel height

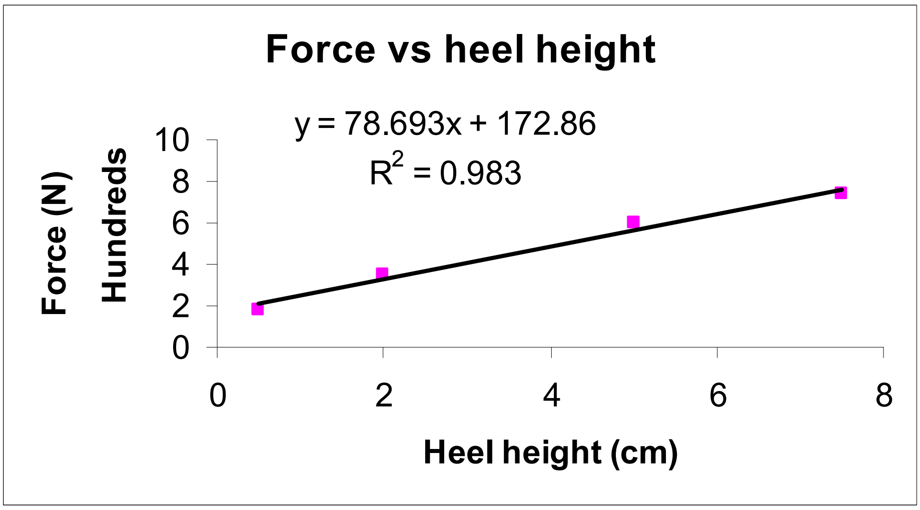

Figure 11 – Graph of Force vs. heel height

The results have been recorded from a range of heel height values, from no shoes to shoes of 7.5cm in height. Measurements were taken and the max peak was recorded from each force given, from the different heel heights. The max peaks at the different heel heights have been shown in figures 12, 13 and 14. The max peak value was taken allowing for the force to be recorded when the whole body is on the force plate.
The figure 6, 7, 8 and 9 shows photos of the shoes used in this experiment, of different heel heights.

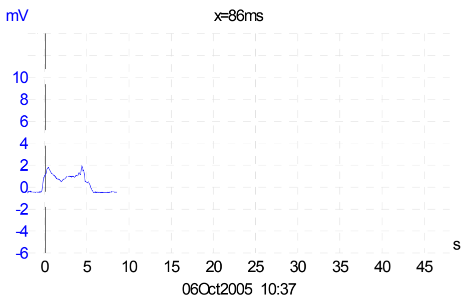

Figure 12 - Max peak from the Pico scope for 2 cm high shoes

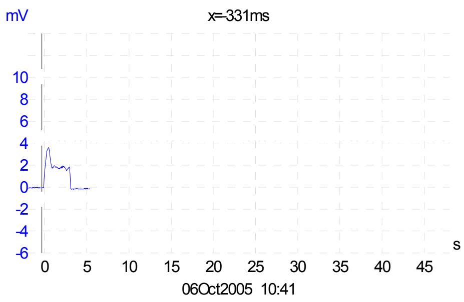

Figure 13 - Max peak from the Pico scope for 5 cm high shoes

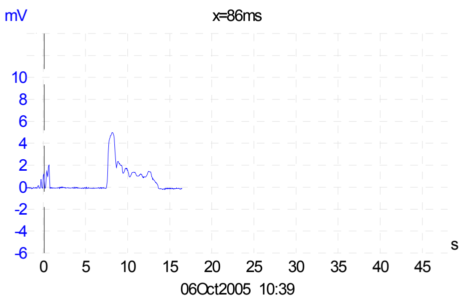

Figure 14 - Max peak from the Pico scope for 7.5 cm high shoes

To measure stress in the bones the formula,

σ=F/A was used.

The results of the stress found at different heel heights are shown in Table 4. The graph of the stress versus heel height is shown in figure 15. This graph shows a linear line of equation (y = -36466x2 + 803386x + 806616).

Force(N)	**Heel Height (cms)**	**Stress (Pa)**	**Force (3 Sig. Figs.)**	**Stress (3 Sig. Figs.)**
184.1765	0.5	1196417	1.84E+02	1.20E+06
349.8784	2	2272823	3.50E+02	2.27E+06
601.5988	5	3908008	6.02E+02	3.91E+06
736.165	7.5	4782155	7.36E+02	4.78E+06

Table 4 – Table of Stress found at different heel heights

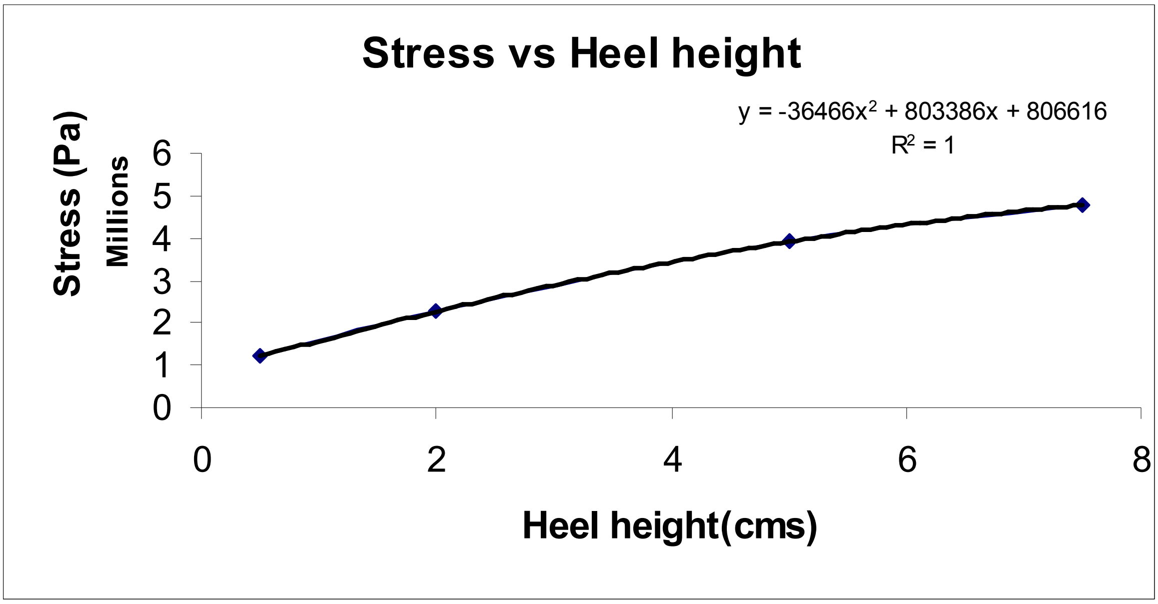

Figure 15– Graph of Stress vs. heel height

For strain

$\varepsilon = \Delta L/L_o$ was used .

By applying Hooke's law for a linearly elastic material, in this case bones, $F/A = Y\Delta L/L$, where Y is the Young's modulus.

Results for the strain on foot at different heel heights are shown in table 5. The graph of the strain versus heel height is shown in figure 16. This graph shows a linear line of equation (y = -5E-06x2 + 0.0001x + 0.0001).

Force(N)	**Stress(Pa)**	**ΔL(m)**		**hHeel height (cm)**	**Strain**
184.18	1196417.18	6.56 E -06		0.5	1.64 E -04
349.89	2272823.18	1.25 E- 05		2	3.11 E -04
601.60	3908008.31	2.14 E -05		5	5.35 E -04
736.17	4782155.39	2.62 E -05		7.5	6.55 E -04

Table 5 – Table of strain found at different heel heights

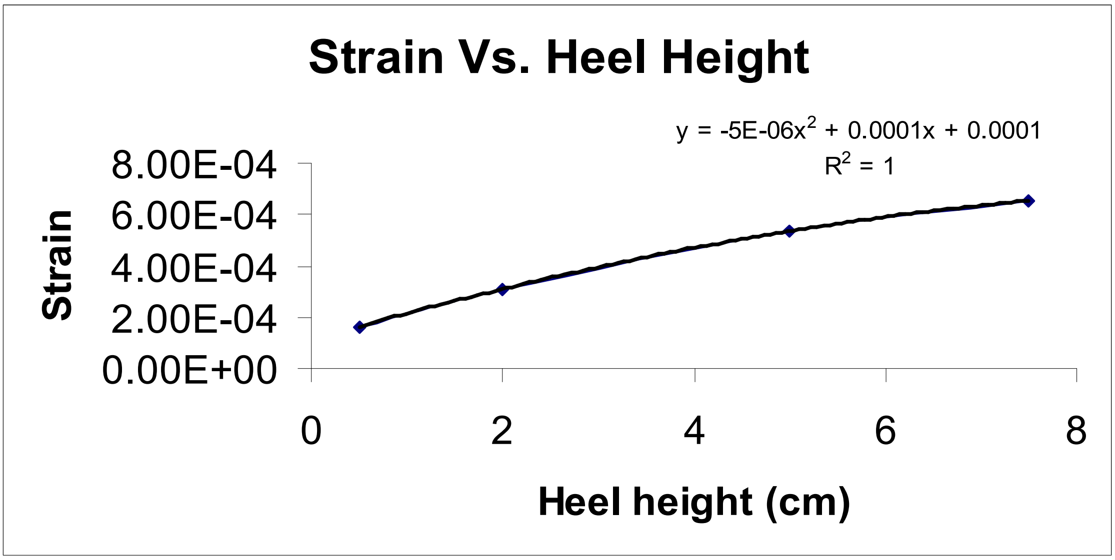

Figure 16 – Graph of Strain vs. heel height

Discussion

This experiment was designed to test the effect that different heights of high heels have on the balls of the foot when in a natural standing position. The results showed a clear trend of increasing force with increasing heel height.

The first step, creating the standard curve, was introduced because of limitations in the equipment available. The force plate/Pico scope combination only allowed for voltages to be read. So a compromise had to be made and a standard curve was created using known forces (weights) (table 1 and figure 5). This caused all results thereafter to be inaccurate as the standard curve was merely a "best fit" curve.

However after this original drawback, the experiment ran smoothly. The expected trend was observed form the onset, with a clear pattern emerging in the raw data collected from the Pico scope, the voltages, as shown in figures 8, 9 and 10. These increased with increasing heel height and were the first indication of the direction in which the results were heading.

From table 3 it is clear to see that once the voltages were translated to force using the equation derived from the standard curve ($y = -9.2354x2 + 193.41x$), the results obtained were consistent with what was expected, that force would increase with heel height (figure 7).

Tables 4 and 5 shows the final results, which satisfy the aim of the experiment, the calculations and comparison of the stress and strain placed on the metatarsal bone in the balls of the foot at the varying heel heights. The results obtained from these calculations (figures 15 and 16) were also consistent with the trends observed in the results of the varying voltage as well as the force. As heel height increases (i.e. as elevation of the heel off the ground increases) so too does both the stress and strain.

The graph of the heel height vs. stress or strain is seen to be a polynomial. This is reasonable because there is a maximum stress and strain which can be put on the foot by simply increasing the elevation of the heel, and this is that which is experienced when the metatarsal bone is vertical with the weight of the body above it. Hence the graphs obtained from the results of the experiment are appropriate (figures 15 and16).

However there were several factors of the experiment which could have been refined in order to make the experiment more accurate. There were a few assumptions made by the project team which may have lead to some inaccurate results as well as some compromises which had to be made in order for the experiment to work with the equipment and resources available.

One such assumption made for this experiment involves stepping on the force plate. The force should have been the same every time an individual stepped onto the force plate; therefore, it was assumed that the force was the same for each individual result. The equation of standard curve used was also assumed to be correct in calculating force from the voltage reading.

Experimental errors involve the use of the protocol and reading of the graph. The protocol, the Pico scope, had not given accurate values, and had needed re-zeroing every time a voltage was recorded. This also led to inaccurate graphs. Reading of graphs may have also been less accurate, as there would have been uncertainties involved. Also in calculating the stress and strain, the Young's modulus found was not certain as the Young's modulus varied from different sources.

Although results have been provided by using only the weight of the experimental individual, if another individual with different weight had been used in the experiment, then the result could vary. This replicate could make the result more accurate. There was also an insufficient number of the variable, the different heel heights, and only 4 data points were collected. If a greater number of differing heel heights had been used, a more accurate result could have been obtained.