Theses and Dissertations

2015

How human musculoskeletal system deals with the heel strike initiated shock waves

Yueyang Zhao
Lehigh University

How human musculoskeletal system deals with the heel strike initiated shock waves

by

Yueyang Zhao

A Thesis

Presented to the Graduate and Research Committee

of Lehigh University

in Candidacy for the Degree of

Master of Science

in

Mechanical Engineering

Lehigh University

06/24/2015

Thesis is accepted and approved in partial fulfillment of the requirements for the Master of Science in Mechanical Engineering.

How human musculoskeletal system deals with the heel strike initiated shock waves

Yueyang Zhao

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Date Approved

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Dr. Arkady Voloshin, Thesis Advisor

_____

Dr. D. Gary Harlow, Chairperson of Department

ACKNOWLEDGMENTS

My name is Yueyang Zhao. I got my B.Sc. in Energy and Power Engineering from Huazhong University of Sci. & Tech., China, in 2012 and M.Sc. in Mechanical Engineering from Lehigh University in 2015. My research interest area is heat transfer, fluid mechanics and Microfabrication.

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ABSTRACT

Objective   The objective for this work was to investigate how the human musculoskeletal system deals with propagation and attenuation of the shock wave initiated at the heel strike. An experiment was designed to evaluate the shock wave on both tibial tuberosities and forehead. By analyzing data collected from the experiments, this work aimed to find how the human body could attenuate the heel strike initiated shock waves and to protect the head from overloading.

Design   30 volunteers were run on a treadmill for two minutes at four different progressive speeds and the accelerations were recorded from both tibial tuberosities and forehead by using skin-mounted accelerometers.

Background   There has been increasing interest in the effects of shock waves on the musculoskeletal system. Voloshin and Wosk [1] examined the values of the amplitude of the propagated waves, which leads to the conclusion that the human locomotor system possesses reduced the heel strike initiated shock waves and tries to prevent overloading of the head from insufficiently attenuated shock waves [2, 3]. Voloshin [3] rated effects of running shoe to attenuate shock waves. It was found that in absolute terms there is no particular shoe that has best performance in absorbing shock waves for all the subjects. Voloshin, Bejjani, Halpern and Frankel [2] found out that the percussive nature of Flamenco dance correlated with increase in urogenital disorders, as well as back and neck pain and this may be related to the shock waves generated by the Flamenco dance.

Method   30 young healthy volunteers participated in this study. Each subject was walking or running on the treadmill at four different progressive speeds for 30 seconds at each speed. The heel strike induced shock waves were recorded on both tibial tuberosities and forehead. MATLAB and EXCEL were used for data analysis.

Conclusion   The data analysis reveals that the heel strike induced shock waves recorded on both tibial tuberosities and forehead increases when the walking or running speed increases. However, the heel strike induced shock wave on both tibial tuberosities increases more quickly compared to that of the forehead. The result supports the conclusion that human body, as a natural shock absorber, tries to attenuate invading shock waves in order to protect the head from exposure to excess loading from the heel strike initiated impact wave.

1 Introduction and Background

1.1 Introduction

Running has become more and more popular. Due to the increase in popularity of running as an exercise, there has also been an associated increase in injuries [4, 5, 6 ,7]. The injuries are very often caused by the heel strike induced shock waves [6, 8]. After the foot strike, the foot experiences vertical loads of nearly three times the body weight.

There has been increased interest in the effects of shock wave on the musculoskeletal system while walking and running. Those activities generate shock waves that are propagated along the human musculoskeletal system and are suspected as one of the main reasons for joint and skeleton degeneration. For this type of dynamic loading, the attenuating properties of the musculoskeletal system are of primary interest.

Attenuation of shock waves mainly occurs in the joints. In order to attenuate those shock waves, increased muscular activity is needed [6, 9]. It was shown that the reflex is most effective for damping lower frequencies, while bone and soft tissue attenuate peak vibrations at higher frequencies [1].

The foot is the first organ that deals with the heel strike induced shock wave. Gait studies have shown that heel strike triggers an impulse wave of 0.5-25 'g' (where 1 g = earth's gravitational field, or 9.8 m/s2) that is clearly noticeable at the knee, hip and forehead levels [10]. This wave is attenuated by a factor of near 1.5 at the knee joint while walking barefoot. The external environment of the foot (e.g. the shoes and the floor) can be manipulated to attenuate shock waves that invade the musculoskeletal system. Similar pattern is maintained during high-heel walking [11], however, the amplitude of the shock waves invading the human musculoskeletal system when walking in high heel shoes is nearly twice of that in low heel gait. In general, shoes modify dynamic [12] behavior of the foot and provide some degree of protection by modifying and dissipating heel strike initiated shock waves.

1.2 Background

A number of researchers have investigated the influence of the heel strike on human body [2, 3, 11]. Voloshin and Wosk [3] examined the absolute values of the amplitude of the propagated waves. The examination leads to the conclusion that the human locomotor system tries to prevent overloading of the head from insufficiently attenuated shock waves. The study also points out the contemporary methods for examination of the human musculoskeletal system may be improved by using the proposed non-invasive in-vivo technique for quantitative characterization locomotor system's shock absorbing capacity. Voloshin(1986) [11] rated run shoe impact by testing how well any pair of shoes absorbs the shock and transmits the impact generated shock wave through the body. The results show that here is no one shoe that gives the best performance in absorbing shock waves for all the subjects. As it is known [2], the Flamenco dancer acts on the floor like a drummer. The percussive footwork during dancing generates a series of shock waves which impose unusual demands on the musculoskeletal system. Voloshin, Bejjani, Halpern and Frankel (1989) [2] investigated biomechanical aspects of this task and ways to reduce the amplitude of the shock waves by the in-shoe viscoelastic insoles. The results show that the percussive nature of the dance, which is, urogenital disorders, as well as back and neck pain, may be related to the shock waves generated by the Flamenco dance form. Moreover, use of the insoles seems to reduce the amplitude of dynamic loading recorded on the tibial tuberosity of the dancer by 9%-29% depending on the dance and performer [11].

2   Methods

2.1 The devices

2.1.1 Accelerometer

An accelerometer [13] is a device capable to measure acceleration. Accelerometers usually rely on the piezoelectric effect of quartz or ceramic crystals to generate an electrical output that is proportional to applied force. A force applied to a quartz crystal

lattice structure alters alignment of positive and negative ions, which results in an accumulation of these charged ions on opposed surfaces.

The applied force is proportional to acceleration. Electrodes collect and wires transmit the charge to a signal conditioner that may be remote or built into the accelerometer. Sensors containing built-in signal conditioners are classified as Integrated Electronics Piezoelectric (IEPE) or voltage mode; charge mode sensors require external or remote signal conditioning. Once the charge is conditioned by the signal conditioning electronics, the signal is available for display, recording, analysis, and control. The sensitivity of the accelerometers used in this study was 10 mv/g.

Figure 1 Accelerometer mounted to the holder

2.1.2 A/D Converter

An analog-to-digital converter (A/D) [14] (MODEL 480D06, PCB) is a device that converts an analog physical quantity (voltage in our case) to a digital values that represent the quantity's amplitude. An A/D performs the conversions at preset frequency or sampling rate.
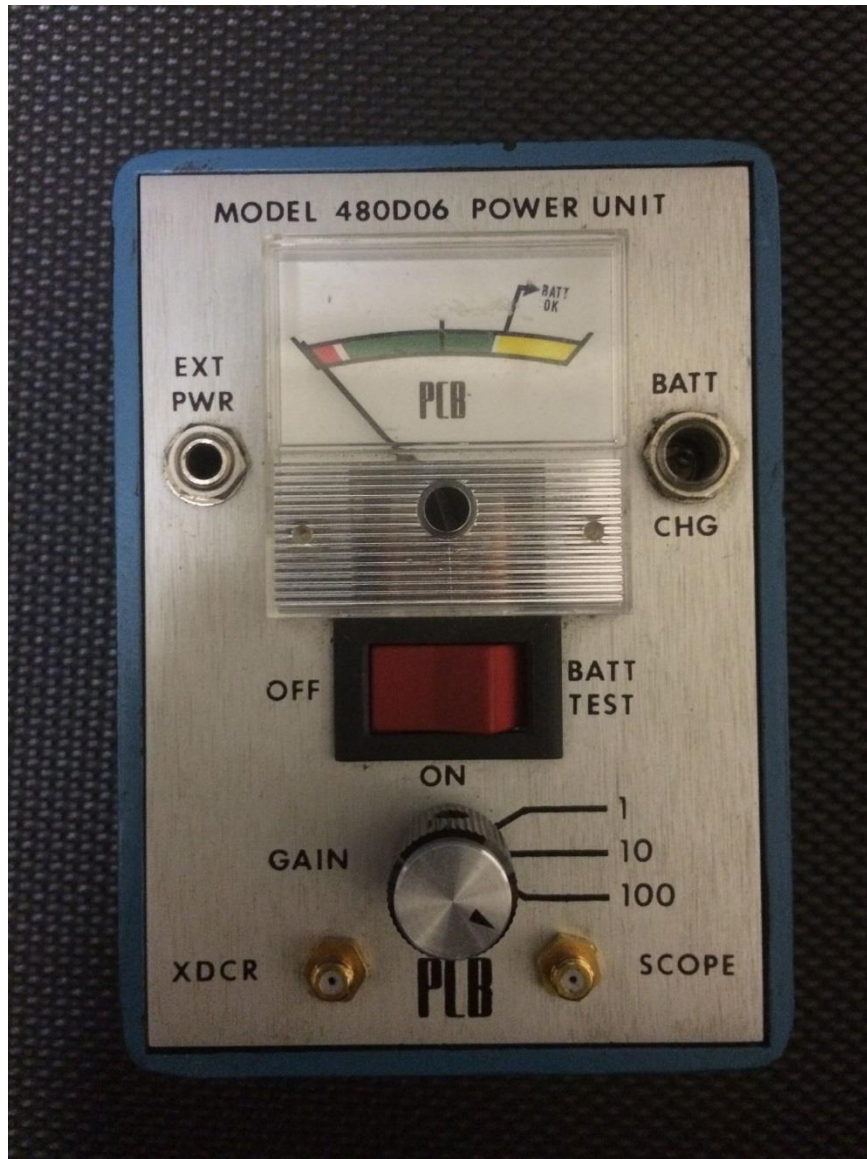
Figure 2 A/D converter

2.2 Experimental Procedure

30 undergraduate students taking a Biomechanics laboratory course, randomly selected, participated in this study. All subjects were in good health. No histories of muscle weakness, neurological and musculoskeletal disease, or drug therapy have been recorded. To ensure the uniformity of the experiment conditions, all subjects were asked to run on the same treadmill (SMOOTH 9.3P, Smooth Fitness, Mt. Laurel, NJ, USA) and were instrumented with the same piezoelectric accelerometers. Their height, weight and gender were recorded. The subjects were asked to walk and run at prescribed speeds: 0.894 m/s (2 mph), 1.341 m/s (3 mph), 1.788 m/s (4 mph) and 2.24 m/s (5 mph).

Experiments were performed on a treadmill so that the heel strike induced shock waves can be precisely monitored. Each volunteer was asked to walk or run on the treadmill for two minutes. These two minutes were divided into four equivalent periods, each period lasts 30 seconds. For each period, the subjects were asked to walk or run on the treadmill with the prescribed speed of 0.894 m/s, 1.341 m/s, 1.788 m/s and 2.24 m/s. The subjects walked at two relatively slower speeds and ran at two relatively faster speeds.

Lightweight accelerometers (303A02-SN-9227, PCB) were used for data acquisition. They were attached at both tibial tuberosities and on the forehead. Those accelerometers acquired shock waves propagated in the longitudinal directions of the human body.

Each accelerometer was attached externally to the point of measurement by a metal holder strapped on the skin by Velcro strips as tightly as possible, but not to cause any discomfort to the subject. This attachment can measure the amplitude of a shock wave as was shown in the earlier works [10, 15, 16].
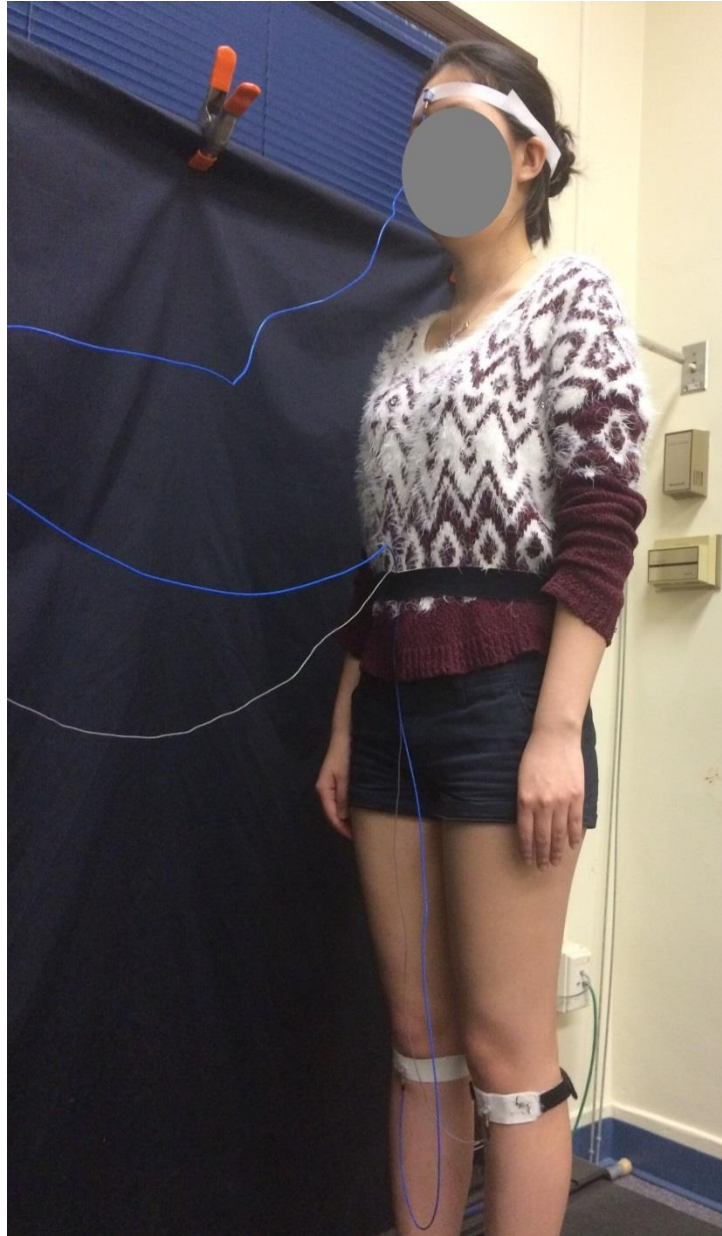
Figure 3 Accelerometers placed on both tibial tuberosities and forehead

During a particular test, acceleration data were acquired for 30 seconds by an A/D converter at a sampling rate of 500 Hz per channel. This setting provided information on about 30 heel strikes, depending on the gait velocity.

For each subject a four column txt file was created by MATLAB to record the data of accelerations. The first column of the file is the experiment time (s) which is 30 seconds

for each speed. The second column is the acceleration on the left tibial tuberosity (g). The third column is the acceleration on the forehead (g). The forth column is the acceleration on the right tibial tuberosity (g). The repetitive nature of the test is evident from the similar responses at two consecutive tibial tuberosities strikes (Figure 4). In order to exclude possible gait modifications, the subject was not informed when exactly the data was acquired.

To assure that the subjects could walk or run comfortably on the treadmill without damaging the wires that connect the accelerometers to the A/D converter, the wires were arranged along the body. All the accelerometers were oriented upside down for convenience of connections. Therefore, all inputs from both tibial tuberosities and forehead were inverted.

After attaching the accelerometers to each subject, the first step of the experiment was to test the magnitudes of the shock waves originated at the three test points. Each accelerometer was tested separately by software package named Instacal 32 [17]. The procedure to operate the Instacal 32 is described in Appendix B.

After testing all three channels, the subject was asked to proceed with the experiment. All data was recorded by using a MATLAB code. Each subject was asked to walk or run for 30 seconds at each speed. Therefore, 15000 samples were collected for each accelerometer. The operator clicked the RUN button in MATLAB after the subject had walked for a few seconds. The purpose for the few seconds delay was to make the subject walking or running into a stable state, so that a usable figure could be plotted. After clicking the RUN button, MATLAB would collect data from accelerometers for 30 seconds. After 30 seconds MATLAB working, figures (Figure 4 and 5) were plotted by MATLAB and displayed on the screen. The amplitude of the shock wave recorded on the forehead is about 10 times lower than that of the both tibial tuberosities. The converter connected to the forehead was set up to multiplication factor of 100 and the converter connected to the tibial tuberosities was set up to multiplication factor of 100. The data

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recorded by MATLAB has units of voltage ("volt"). It has to be converted to the units of the acceleration ("g"). The sensitivity of the accelerometer is 10mv/g. The multiplication factor on the converter was 10 for the tibial tuberosity accelerometers and 100 for the forehead accelerometer. For example, the data of left tibial tuberosity recorded by MATLAB was 0.326 volts and the multiplication factor on the converter was 10. So the voltage was 32.6 mv and the acceleration was 3.26 g. Similarly, when the data recorded on the forehead was 2.35 volts, the acceleration on forehead was 2.35g.

After each period of 30 seconds, the subject was asked to stop and the data was checked to ensure that the recorded data was reasonable. Then the data was saved and the subject started to walk or run at the next speed.

For data analysis, a MATLAB procedure was developed to utilize the known running speed and to locate the positions and amplitudes of each heel strike generated shock wave. It proceeded automatically and detected all occurrences of the shock wave at the tibial tuberosities and forehead. Since there was always a possibility of "bad" data (e.g. subject stumbled or misplaced the foot), the detected strikes were shown on the screen and confirmed by an operator.

3   Data Analysis

3.1 Data acquisition

Four data files were generated for each subject, each corresponding to one of the four speeds. The recorded files were analyzed by a MATLAB code called "Find Peaks" that was used to find the amplitude and location of the recorded shock wave. The anticipated time interval in seconds between two adjacent peaks was inputted. This interval for both tibial tuberosities was in the range of 0.7 to 1.2 depending on the speed the subject was walking or running. The time interval for the forehead was always half of the value for the tibial tuberosities, based on relevant theories of both ergonomics and kinesiology [1]. The outputs of the MATLAB code were peaks, time of experiment, which was 30 second

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totally, mean standard value and also the figures plotted. Peaks were the data relevant to the results of the experiment,

As mentioned in the introduction of the experiment procedure, all data should be inverted as the accelerometers were turned upside down. Figure 4 shows the sample of the recorded data. The Figure 5 shows the sample of the recorded peak values.
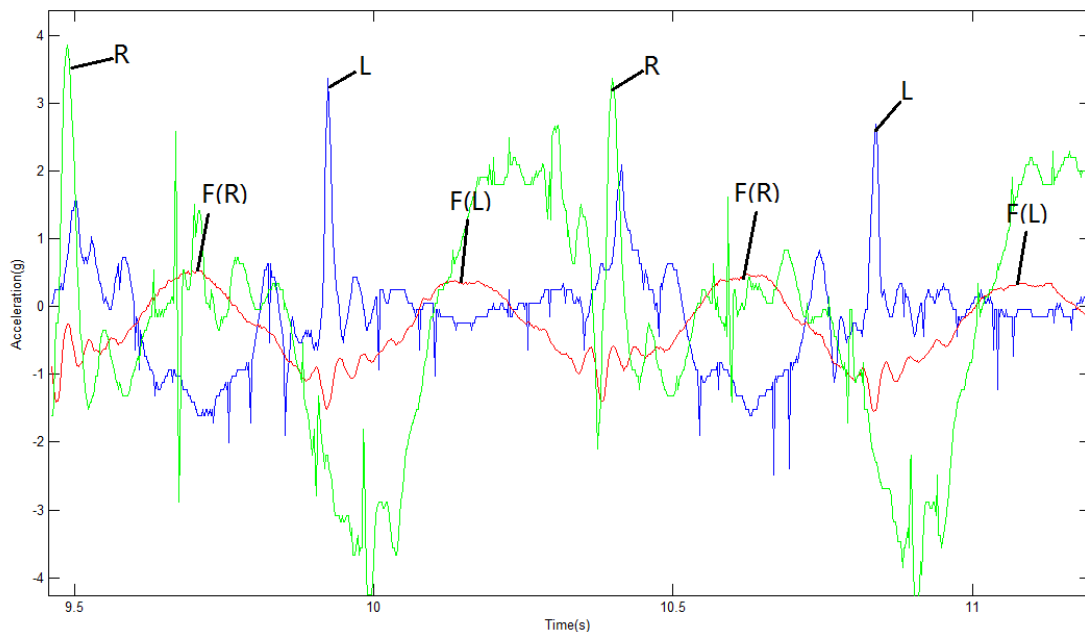
Figure 4 Sample plot of the acceleration recorded on the forehead and both tibial tuberosities. "L" represents the peak acceleration on left tibial tuberosity. "R" represents the peak acceleration on right tibial tuberosity. "F (L)" represents the acceleration on forehead corresponding to the left tibial tuberosity. "F (R)" represents the acceleration on forehead corresponding to the right tibial tuberosity.
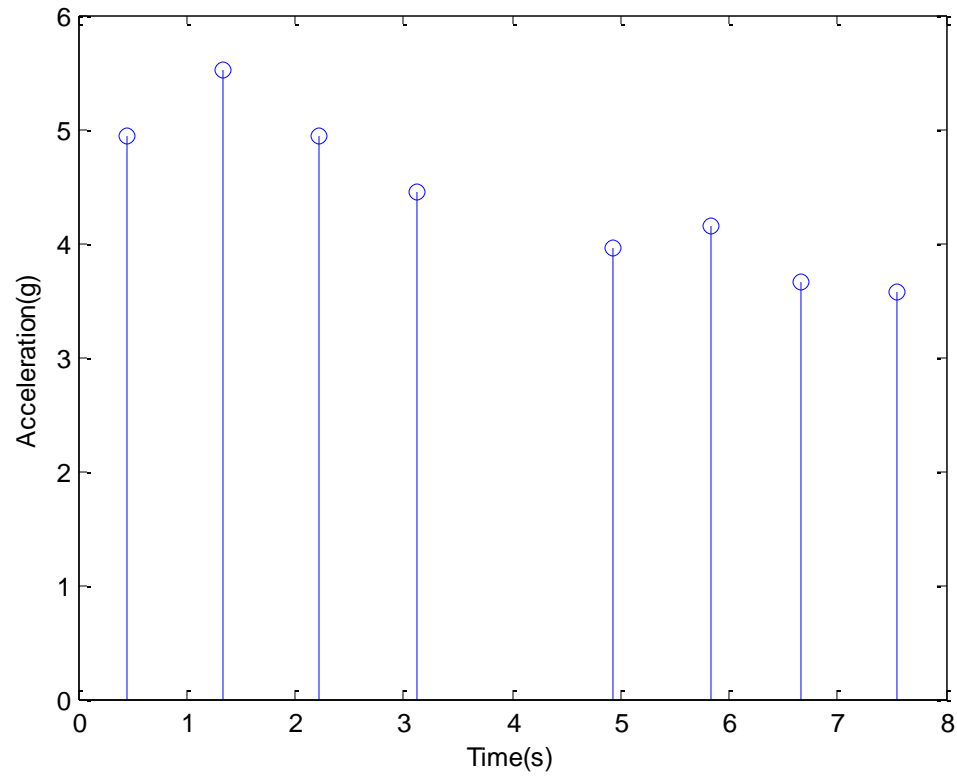
Figure 5 Sample plot of the acceleration peaks on right tibia tuberosity as detected by the software

The peaks of the recoded shock waves were detected by MATLAB (Figure 5) and saved into EXCEL.

3.2 Data selection

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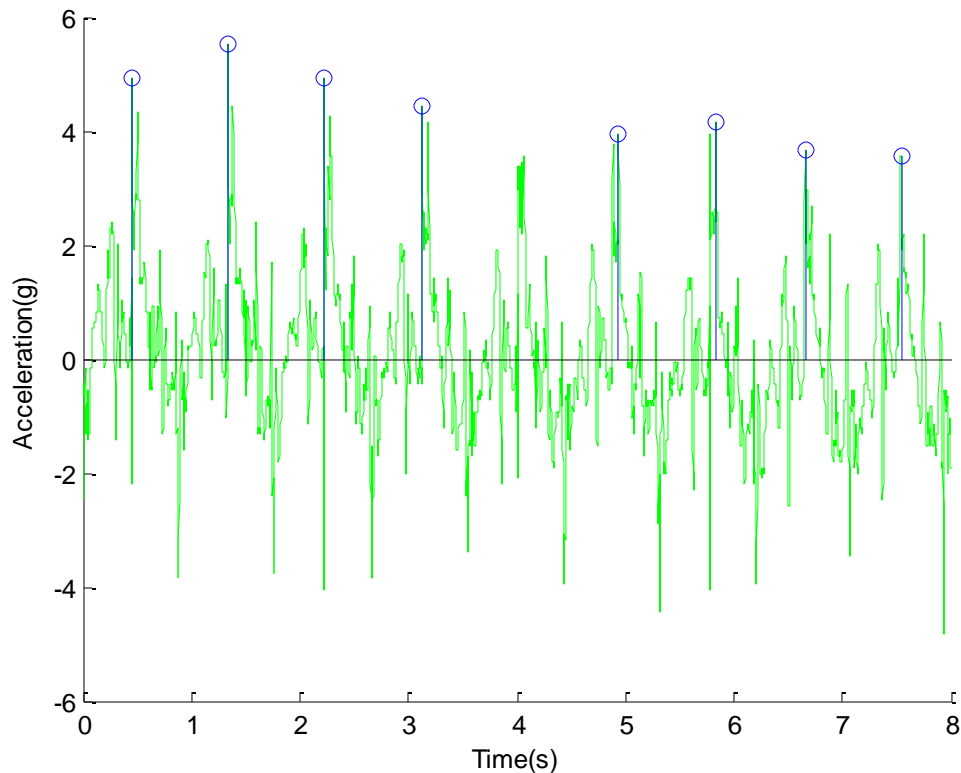
Figure 6 The location and amplitude of each heel strike detected by MATLAB

Figure 6 shows the location and amplitude of each heel strike as measured on the right tibia. Every heel strike could cause shock wave on forehead once. So each heel strike induced the shock wave on tibia was corresponding to one shock wave on forehead. To make the result accurate, every pair of corresponding data of tibia and forehead was detected. To assure that the impact recorded on the both tibial tuberosities correspond to the data recorded on the forehead, some bad peak points were deleted and the blanks were added. As a result, the number of the forehead recorded peaks is equal to the sum of the left and right tibia peaks. Here, for example, the heel strike wave at time 4 seconds was not automatically detected, thus it was added manually.

The acceleration due to the heel strike (Figure 4) measured on both tibial tuberosities also shows the time location of acceleration for both tibial tuberosities and corresponding forehead accelerations.

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Although all the tests were done under the operator's control, it was inevitable that some bad data occurred for some subjects due to poor contact of the accelerometer, low battery in the converter or some other unknown reasons. The bad data was excluded from analysis.

3.3 Data Analysis

We examined the acceleration on forehead and both tibial tuberosities and the ratio of the acceleration on forehead to that on each tibial tuberosity.

The way people walk or run is different from subject to subject. Some people hit the ground harder with their left foot, while the other with their right foot they are walking or running. This is due to the fact that we are not completely symmetrical creatures. Therefore it is meaningless to analyze the average acceleration values as measured on left and right tibial tuberosities. It concerned the acceleration values on high and low side tibial tuberosities in this test.

The data analysis procedure is as follows:

a. Compute the mean average and standard deviation of the data in each column.
b. Use two methods to compute the ratio of the acceleration on forehead to that of left and right tibial tuberosities, respectively. The first method is to calculate the ratio of average forehead data to tibial tuberosities data. The second method is to calculate the ratio of forehead acceleration to the corresponding tibia acceleration, e.g. the same shock wave when it passes the tibial tuberosity and when it arrives at the forehead. Then the average of the ratios is computed. It turns out that the second method is more accurate compared to the first one.
c. Use EXCEL to run a t-test to check whether two arrays are significantly different.

A t-test is a statistical hypothesis test in which the test statistic follows a Student's distribution if the null hypothesis is supported. It can be used to check if two sets of data are significantly different from each other. When the scaling term is unknown and is replaced by an estimate based on the data, the test statistic (under certain conditions) follows a Student's t distribution. As a matter of good scientific practice, a significance level is chosen before data collection and is usually set to 0.05 (5%). When the t-test result is higher than 0.05, this indicates that two data arrays are not significantly different. When the t-test result is lower than 0.05, it means that two arrays are significantly different.

Table D-1 in Appendix D shows the value of peaks data measured by MATLAB. After deleting the bad data caused by the operation and devices errors (e.g. low battery in the converter or accelerometer not touching properly on forehead), there were only ten usable subjects' data and 14 usable tibial tuberosities data could be measured. Table D-2 in Appendix D shows the average accelerations for each subject at each speed. The result of the t-test allows to check if there is significant difference between accelerations at every pair of different speeds.

4   Analysis of Results

The results of the averaged acceleration at the forehead, high side and low side tibial tuberosities are shown in Figures 7, 8, and 9 as a function of the subjects' velocity. Error bars displayed on the images represent the standard deviation. In the Figures, "n.s" denotes insignificant difference while "***" denotes significant difference. To reduce the clatter on the Figures, either "n.s" or "***" were shown (e.g. if only n.s was displayed in the Figure 7, it means the difference is significant for all other velocities).
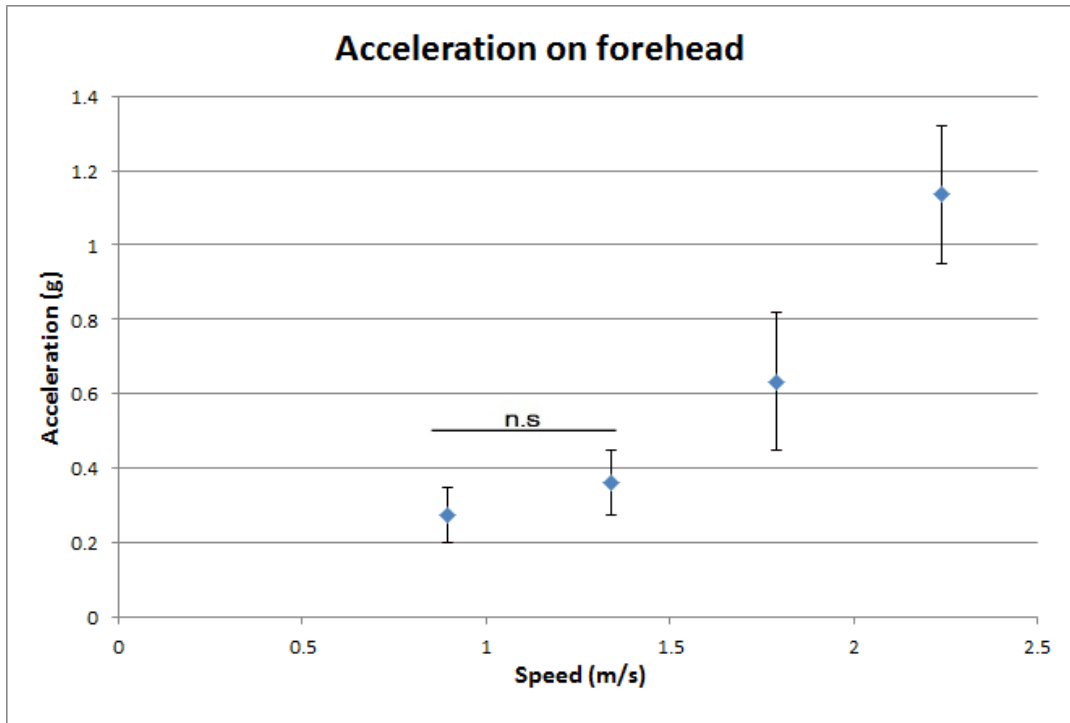
Figure 7 The acceleration on forehead (g)
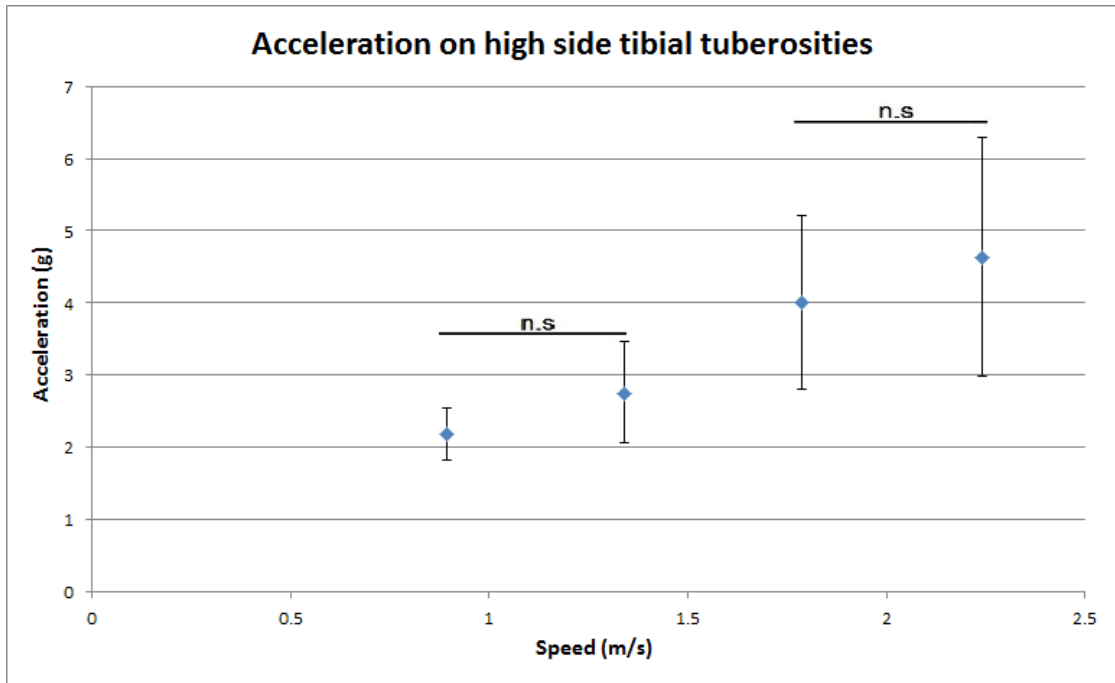
Figure 8 The acceleration on high side tibial tuberosities (g)
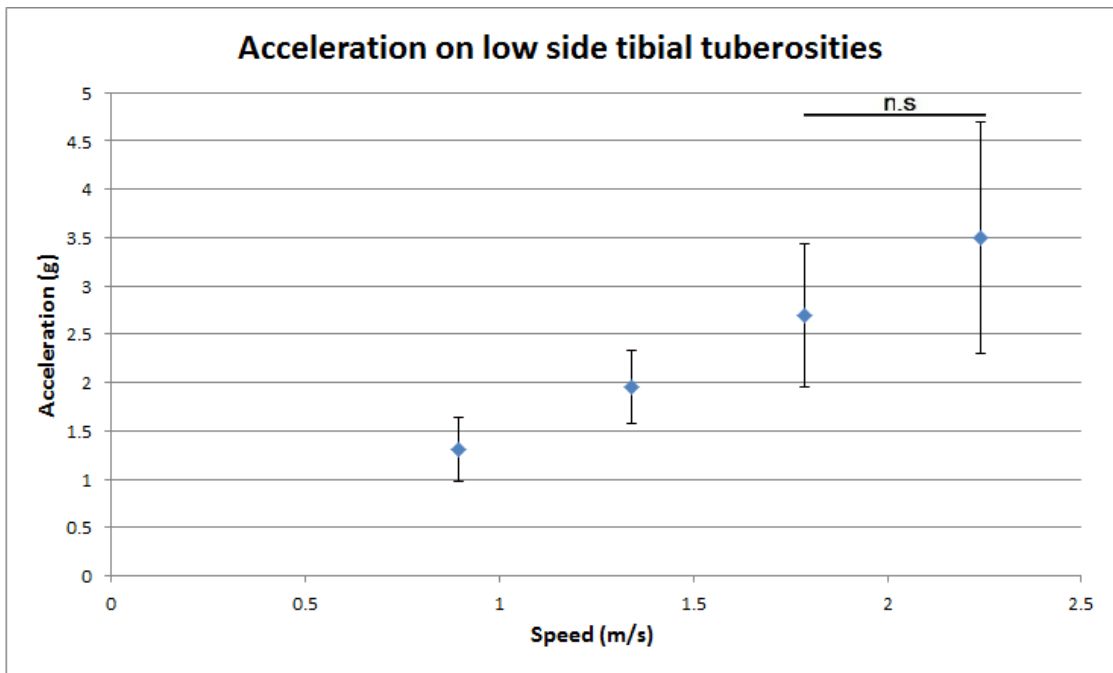
Figure 9 The acceleration on low side tibial tuberosities (g)

The acceleration ratio of the forehead signal to that on the high side, low side and both tibial tuberosities are shown in Figures 10, 11 and 12 as a function of the subjects' velocity.
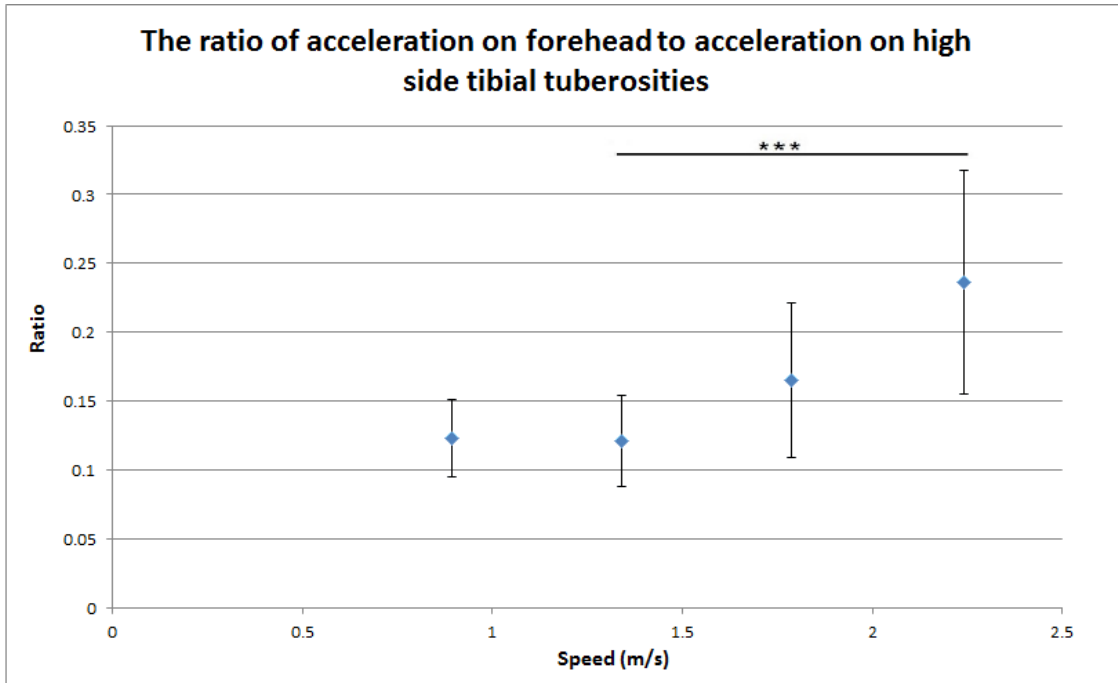
Figure 10 The ratio of acceleration on forehead to high side tibial tuberosities (g)
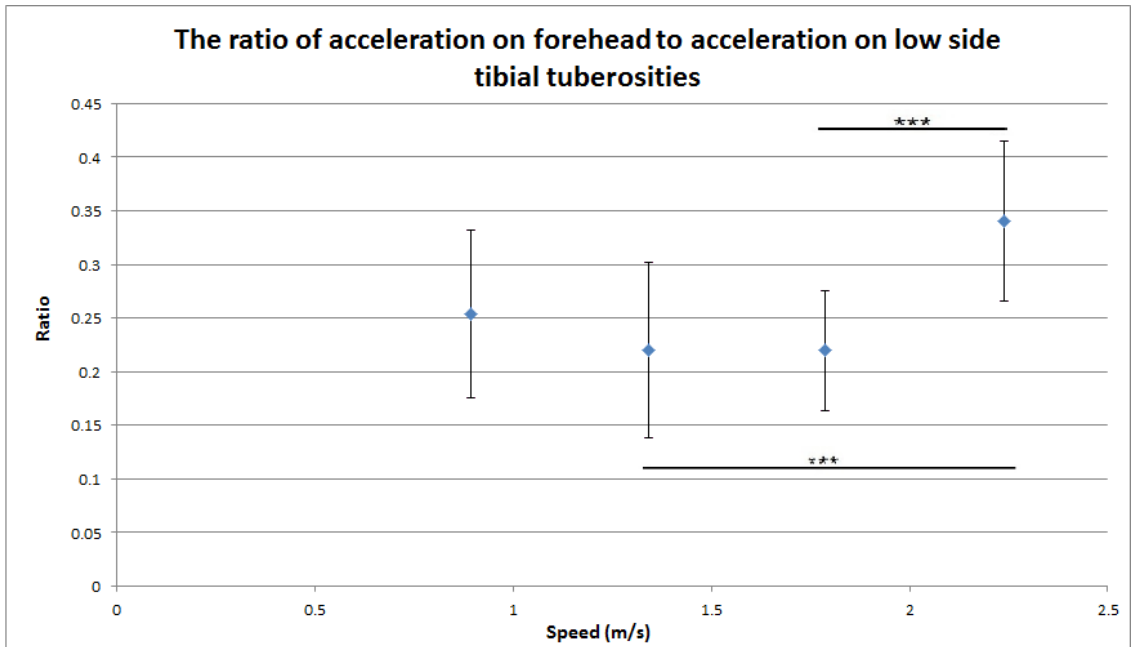
Figure 11 The ratio of acceleration on forehead to low side tibial tuberosities
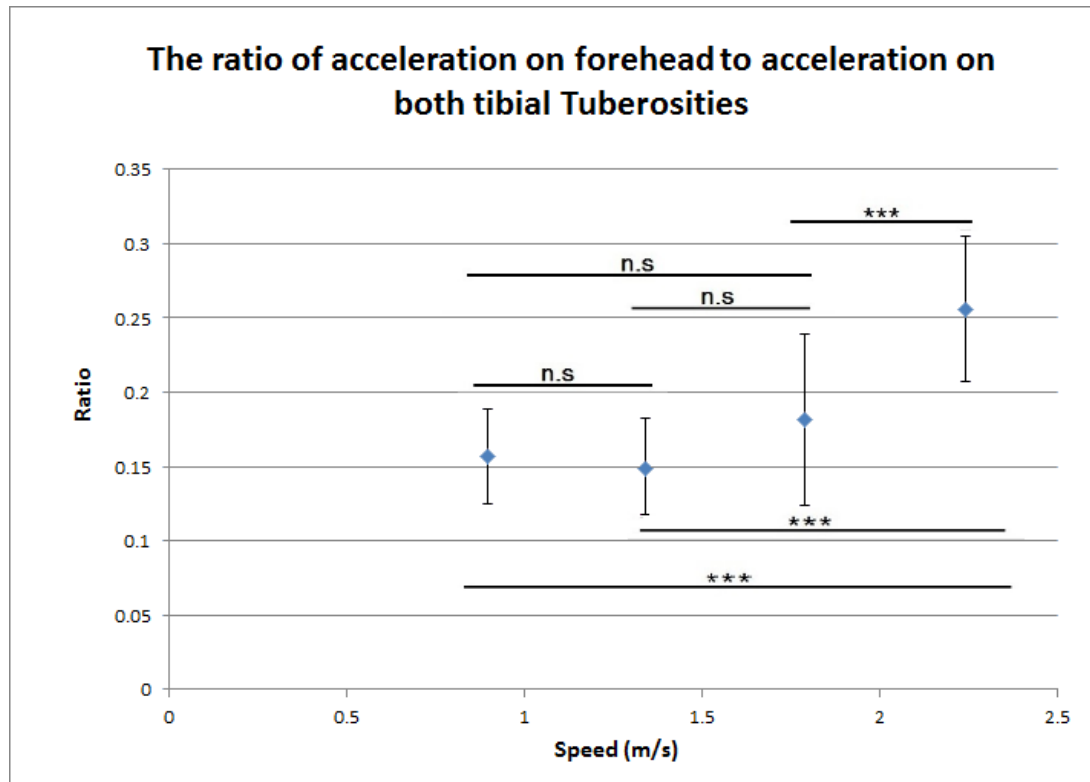
Figure 12 The ratio of acceleration on forehead to both tibial tuberosities

The Figures 7 to 12 show that the shock waves from both tibial tuberosities and the forehead increase when the walking or running speed increases. Moreover, the results also indicate the accelerating increase in the shock waves recorded on both tibial tuberosities and the forehead. What's more, when the speed is at a relatively low level, the increasing rate of acceleration on both tibial tuberosities and the forehead is basically the same. However, when the speed is at a relatively high level, the increasing rate of acceleration on the forehead is faster than that of the two tibial tuberosities. In order to further verify this conclusion, the slope of the acceleration on all the three tested points was computed.
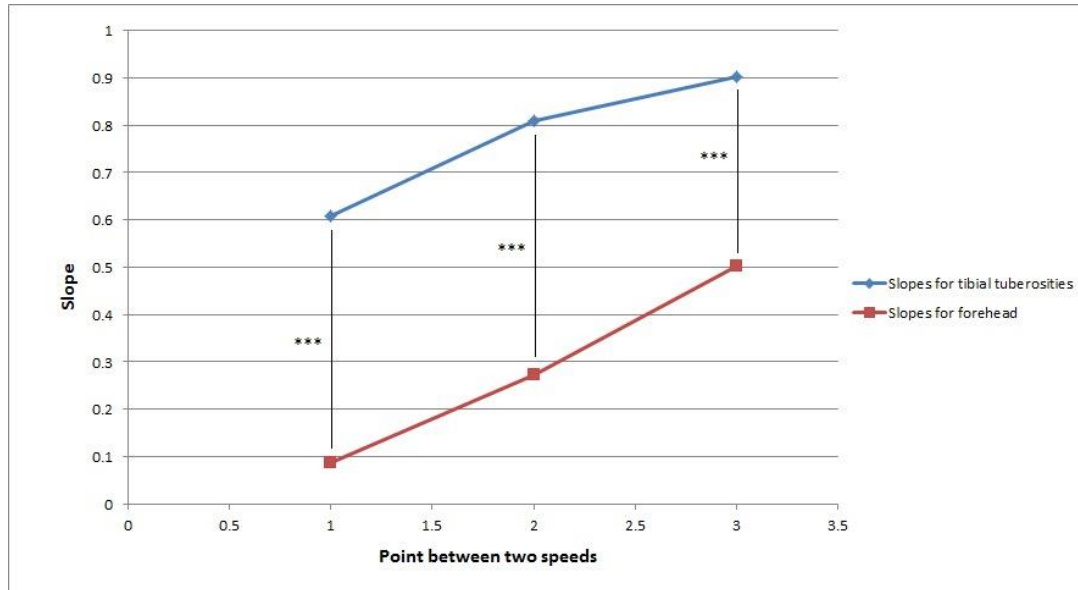
Figure 13 Acceleration change vs. subjects velocity

The points in figure 13 represent the slope for acceleration between every two consecutive speeds. The numbers at horizontal axis means the period between two near speed (e.g. "1" means the period between speed 0.894 m/s and 1.341 m/s). Figure 13 reveals that when the walking or running speed increases, the shock wave from both tibial tuberosities and forehead increases and it also indicates the rate of acceleration increase. The slopes indicate that when the speed increases, the shock waves on the two tibial tuberosities increase faster than that on the forehead.

Effect of Gender on shock wave propagation

In order to check if gender has a significant influence on the result, the data was further divided into two parts by gender.
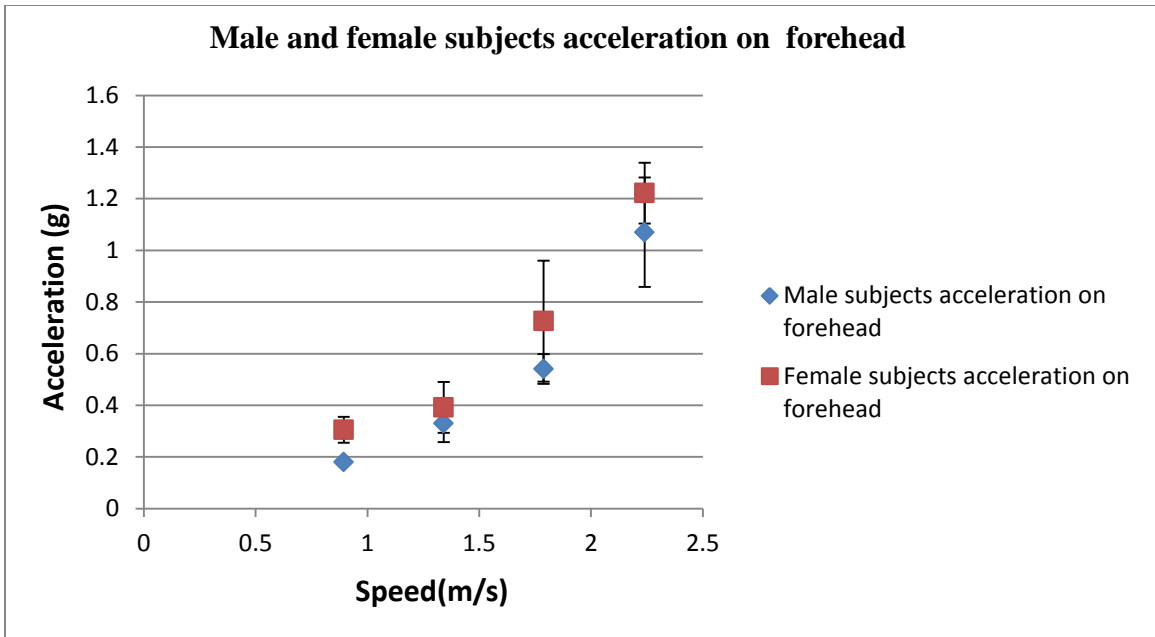
Figure 14 The acceleration on forehead for males and females
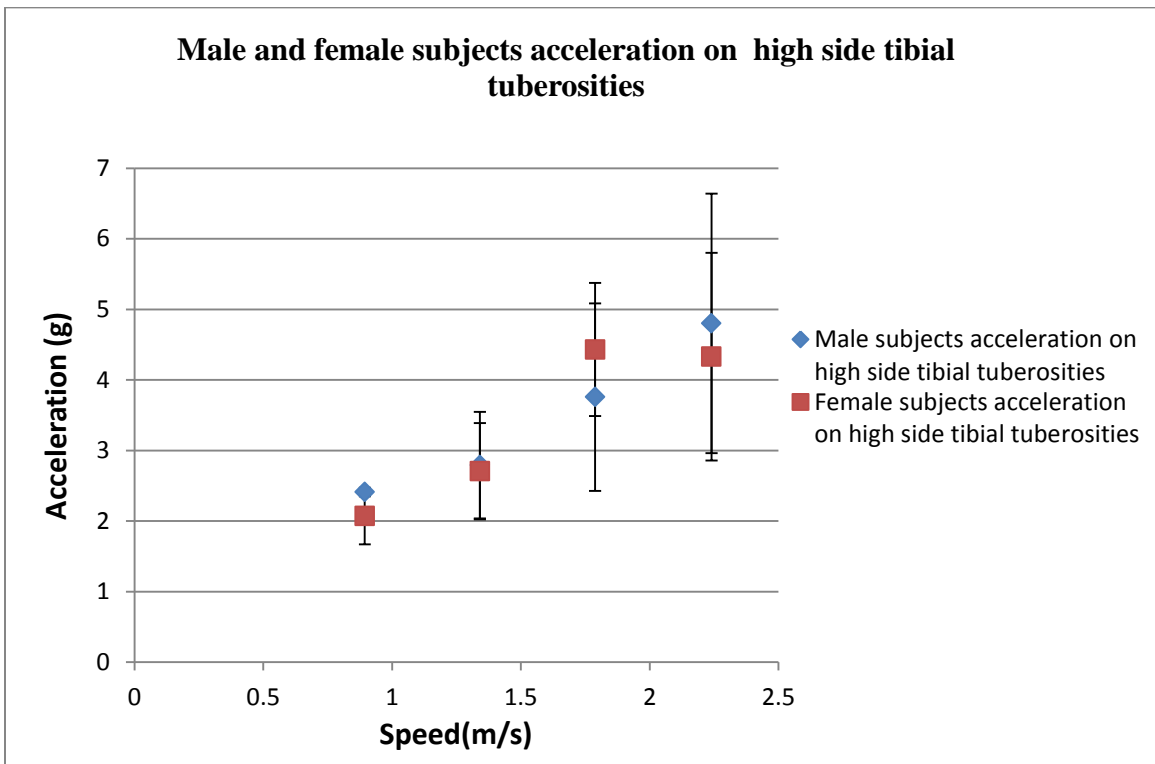
Figure 15 The acceleration on high tibial tuberosities for male and female
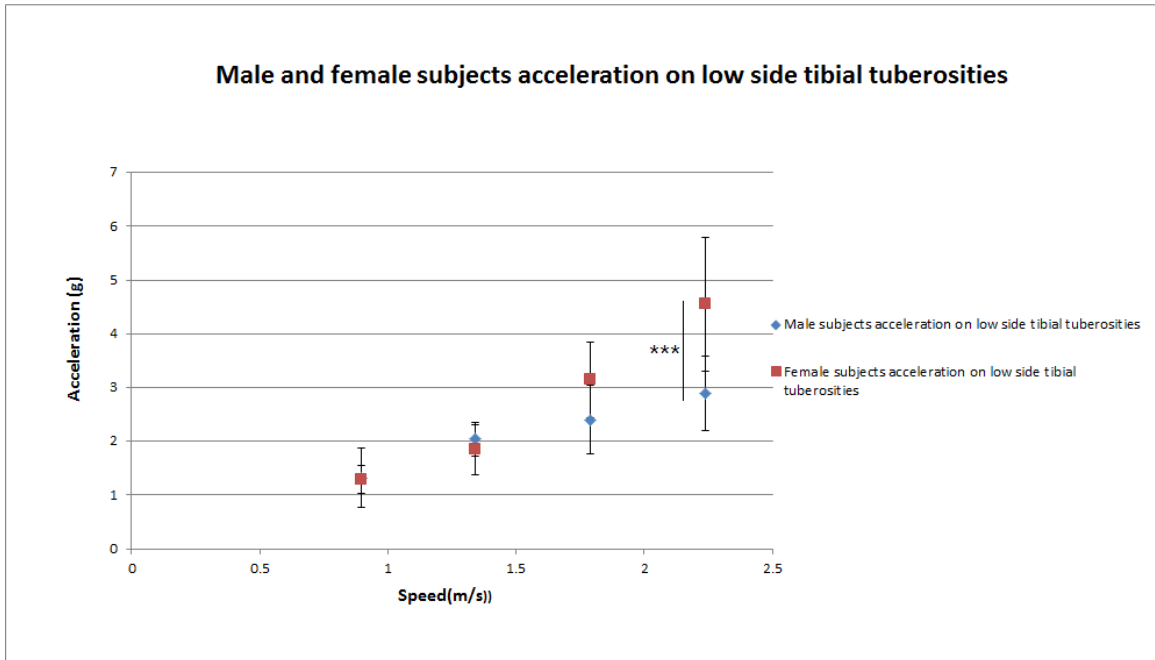
Figure 16 The acceleration on low tibial tuberosities for male and female

A test was run in order to check if there is significant difference between the acceleration at each speed for male and female subjects. The results (i.e. the t-statistics) are shown in the Tables A-1 to A-3 in Appendix A.

The results show that when the speed is at a relatively low level, there is no significant difference in amplitude of shock wave between male and female. When the speed is at a relatively high level, there is, however, a significant difference in amplitude of shock wave between two genders.

5 Time of Flight

In order to find out if gender has a significant influence on the effect of heel strike induced shock wave, we also analyzed the time of flight of the shock wave between the tibial tuberosity and forehead. As the height of all the subjects was recorded, the distance

between one's forehead and tibia could be defined based on the study of body segment parameters [18]. The distance is (1-0.285) times the height of the subject.

The time of each peak point of acceleration on forehead and both tibial tuberosities was detected by MATLAB. The time of flight was measured by finding out the time interval between the amplitude of acceleration on forehead and the corresponding tibial tuberosity. The t-test results for male and female subjects at the same speeds (Table A-4) show that there is significant difference of the time of flight between male and female. As it is shown in Table A-5, neither one's gender or height has a significant influence on the speed of the wave propagation. However, while the speed increases, the time of flight does reduce. Therefore, the velocity of the signal (Table A-6), when it is transferring within the human body, is probably correlated with the amplitude of the shock wave. More specifically, the stronger the shock wave is, the shorter is the time of fight and thus higher is the wave velocity.

6   Discussion and Conclusion

Analysis of the recorded and processed data reveals that for the young, healthy subjects their height and weight are not the determinate elements that influence the shock wave transmission in human's body. As shown earlier [11], the type of shoes was not a factor that influences the heel strike initiated shock wave, although differences in their amplitude can be observed. The effect of the footwear was not considered in this experiment. With the increase of speed subjects are walking or running, the amplitude of the shock wave is also increasing. As it has been shown in the Figures 7, 8 and 9, there is a significant difference in the ways the human locomotor system deals with the foot strike initiated shock waves along the human body. That means as the speed increases, the amplitude of the heel strike induced shock waves increases as well. The Figures 10 and 11 reveal that there is no significant difference between the ratios of forehead to tibial tuberosities. And as shown in Figure 13, when the input from both tibial tuberosities increases, the rate of acceleration increase on tibial tuberosities is higher than that on the

forehead. As a conclusion of this experiment, human body is trying to protect the head from the heel strike induced shock waves is an inherent part of normal function and well-being of the healthy human musculoskeletal system. It is well known that any wave is always attenuated while propagated in a media. But while the amplitude of the heel strike induced shock waves become larger with increase in speed, it was not clear whether the body attenuation would also protect the human's head. This would be a good direction for a further study on the attenuation of the heel strike initiated shock waves by human body. This research could be extended in the following aspects in the future. It may include more subjects in the experiment in order to get better analysis of the significance of the differences. Moreover, the study could be improved by also measuring the acceleration on both the two tibial tuberosities and forehead when the subjects are asked to run at higher speeds or do exercise that could cause greater shock waves. Thus, this will make it possible to study whether the human body could still protect the head when the shock waves are reaching much higher level.

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Appendix A

T-tests tables

Table A-1 T-test on forehead at the same speeds between male and female

Velocity (m/s)	T-test result
0.894	-
1.134	0.349
1.788	0.176
2.240	0.322

Table A-2 T-test on high tibial tuberosities at the same speeds between male and female

Velocity (m/s)	T-test result
0.894	0.845
1.134	0.141
1.788	0.187
2.240	0.533

Table A-3 T-test on low tibial tuberosities between male and female

Velocity (m/s)	T-test result
0.894	0.947
1.134	0.371
1.788	0.077
2.240	0.0178

Table A-4 T-test on time of flight at the same speeds between male and female

Velocity (m/s)	T-test result
0.894	0.375
1.134	0.0340

1.788	0.00188
2.240	0.00184

Table A-5 T-test on velocity of the shock wave at the same speeds between male and female

Velocity (m/s)	T-test result
0.894	0.540
1.134	0.0259
1.788	0.0878
2.240	0.294

Table A-6 T-test on velocity of the shock wave at different speeds for all subjects

Velocity (m/s)	T-test result
0.894--1.134	0.234
0.894--1.788	5.68E-09
0.894--2.240	6.39E-12
1.134--1.788	1.486E-09
1.134--2.240	2.76E-14
1.788--2.240	0.240

Appendix B

MCC and Instacal software

Install the MCC DAQ Software

The MCC DAQ Software installation program consists of a series of easy-to-follow dialog boxes that lead you through the installation procedure. To install the MCC DAQ Software, complete the following steps:

1. Insert the MCC DAQ Software CD in your CD drive and wait for the installation

program to start.

If the installation program does not start automatically, use Windows Explorer to browse to the root of the CD, and double-click Install.exe.

The **MCC DAQ** dialog box opens.

All software packages are selected for installation if the requirements for the package are met. If you do not want to install a software package, clear its checkbox.

The **Required dependencies** pane lists the software packages needed to run each MCC DAQ Software package.

Adobe Reader - Adobe Reader is required to open the hardware user's guides.

Microsoft. NET framework - The .NET Framework 2.0 is required to install TracerDAQ, ULx for NI LabVIEW, and the hardware user's guides.

InstaCal is a software utility for installing, configuring, calibrating, and testing MCC devices. MCC devices on a Windows platform cannot be used with Universal Library programs until they are first detected by InstaCal and added to the configuration file. message displays as the device is detected by Windows. A **New Hardware Wizard** runs and installs the drivers required to operate the device.

Note: When installing some MCC devices, such as the USB-2416 Series and USB-2404 Series, an additional **New Hardware Wizard** may display when you install the device. This wizard is required to install additional driver specific to this device. *Do not cancel this wizard* or the device will not install properly.

InstaCal overview

InstaCal is a software utility for installing, configuring, calibrating, and testing MCC devices. MCC devices on a Windows platform cannot be used with Universal Library programs until they are first detected by InstaCal and added to the configuration file.

Installing a device

USB, Bluetooth, and PCI devices are automatically detected by InstaCal and added to the board list after they are connected/ paired to the computer.

From the InstaCal drop-down menu, select **Install** » **Add Board** to display a group of tabs. Each tab lists the devices you can install. Once selected, the device is added to the board list, and remains there until removed.

The InstaCal main screen lists each device that it automatically detects or that was manually added to the board list.

Configuring a device

To configure a device, double-click on the device name to open the **Board Configuration** dialog box. The settings which display are specific to the device selected.

A common configuration task for A/D boards is to set the analog input channel mode to either single-ended or differential.

InstaCal stores hardware configuration settings in a configuration file which is read by the Universal Library when you run an application. To change device settings, stop the UL application and run InstaCal.

Note that Only one application program that calls the Measurement Computing driver can be running at a time. If the device is used by a Universal Library program, changes to device configuration settings can only be made when the program is not running.

Testing a device

InstaCal provides analog and digital tests to determine if the analog inputs and digital bits are working properly. To test the device, select either **Test** » **Analog** or **Test** » **Digital**. A **Board test** dialog box displays with options specific to the selected device.

Analog input tests may include a Loopback test and a Scan test.

Perform a Loopback test to verify the analog connections, and that the basic analog

measurement operation is working properly. With this test, one channel at a time is tested in a slow (non-clocked) sampling mode. You can loop back one of the onboard signals or use an external signal.

Perform a Scan test to sample multiple channels simultaneously at a specified clock rate. The Scan test is a good test of the DMA and IRQ resources assigned to the card. Acquired data can be displayed graphically or numerically.
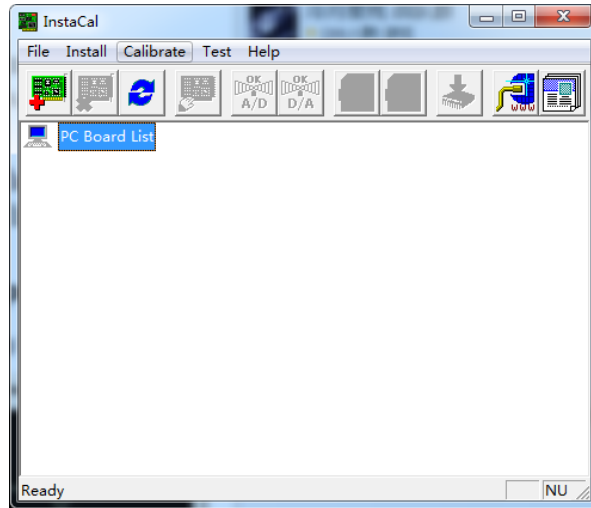
Figure 17 The main interface of Instacal 32

The three accelerometers are corresponding three channels. The channel 0 is corresponding left tibia. Channel 1 is corresponding forehead and channel 2 is corresponding right tibia.

Test channel 0

InstaCal includes options to test the analog and digital features of your MCC hardware. When running internal tests, disconnect your signals or your cable to prevent false failures.

Complete the following steps to run the analog loop back test on the Board# 0 and verify that the channel is generating the proper waveform.

1. Select the **Board# 0 – USB – 1208FS (serial# 172)** on the **PC Board List**.
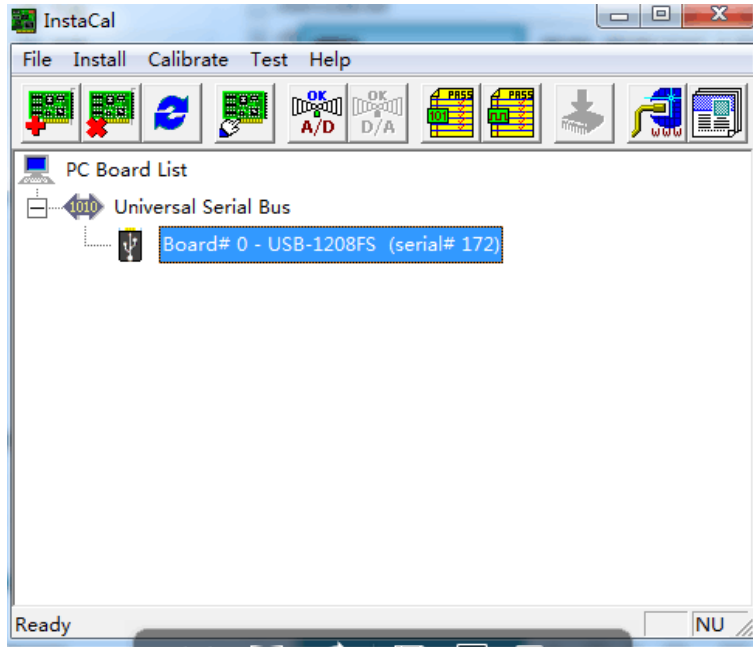
Figure 18 Selection in Instacal 32

2. Select **Test** » **Analog** and select **Ch 0** in the **Input Ch** list.
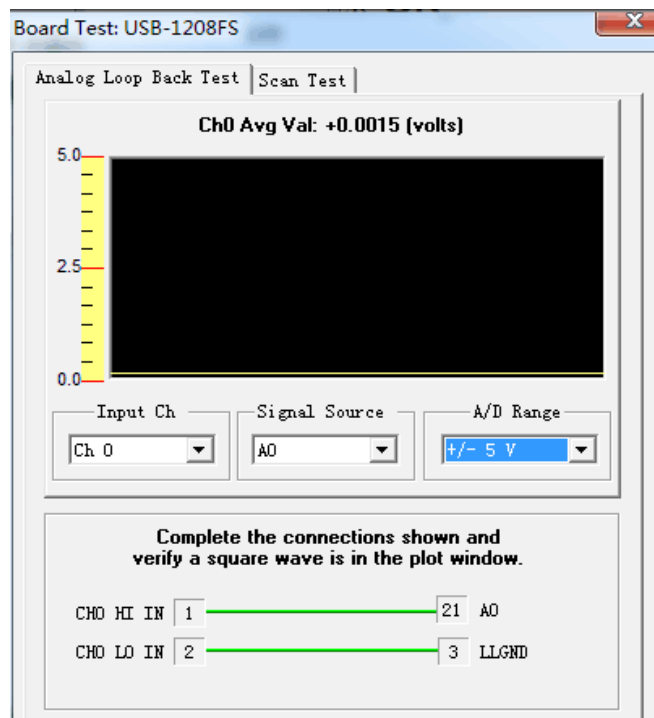
Figure 19 The interface of testing the signal

3. Click the accelerometer very carefully.

Then the image is like below.

Figure 20 The showing of signal test

Appendix C

MATLAB CODE

Data collection code:

```
clc
% First find any open DAQ objects and stop them.
openDAQ=daqfind;
for i=1:length(openDAQ),
    stop(openDAQ(i));
end

%%
% In this example you will acquire data from the PDM 1208FS
% If you are
% unsure about this, refer to Appendix A of the Data Acquisition Toolbox
% User's Guide.

%%
% In this demonstration:
%
% The data source - is the voltage input
%
```

```matlab
%
% The sink - is a channel associated with an analog input object.
%
% Now let's create an analog input object and add a single channel to it.
%ai = analoginput('winsound');
dd='before start1';
ai = analoginput('mcc',0);
% addchannel(ai, [0 1 2]);   % 0, 1, 2   ->3 channels data acquisition
addchannel(ai, [0 1 2 3]);   % 0, 1, 2, 3   ->4 channels data acquisition
%%
% Now, let's set up the analog input object so that we acquire 5 seconds of
% data at 8000 Hz as soon as the object is started.
ai.SampleRate = 500;   %samples/second/ch
ai.SamplesPerTrigger = 15000; %5 sec at 100 Hz = 500 samples % 10sec at 20 Hz 2
chan=400
ai.TriggerType = 'Immediate';

%%
% With the analog input object set up, let's start it and then get the data
% that it collects.
dd='before start';
start(ai)
[d,t] = getdata(ai);
dd='data recorder is';
%    d(1:100,:)
%%
% Now that you're done collecting data, plot it.
plot(t,d);
zoom on

%%%%%% now I can save the data in a file

%ask for file name
path = pwd; % get path to the current directory
fileName1=input('Enter file name NO extension,e.g. data1\n','s')
fileName2=strcat(path, '\');
fileName1=strcat(fileName1, '.txt');
fileName=strcat(fileName2,fileName1);
%%
fid = fopen(fileName,'wt');
for i=1:ai.SamplesPerTrigger
% fprintf(fid,'%12.4f   %12.4f   %12.4f   \n',t(i),d(i,1),d(i,2)); % 2ch
% fprintf(fid,'%12.4f   %12.4f   %12.4f   %12.4f   \n',t(i),d(i,1),d(i,2),d(i,3)); % 3ch
fprintf(fid,'%12.4f   %12.4f   %12.4f   %12.4f %12.4f \n',t(i),d(i,1),d(i,2),d(i,3),d(i,4)); %
4ch
```

```matlab
end

%%
% Previously, you used the GETDATA function to collect 5 seconds of data.
% The only    problem is that GETDATA is a "blocking" function. This means
% that it will wait until all 5 seconds of data have been collected. For
% many applications, this is not what you want. The solution to this is to
% use the PEEKDATA function. For this example, let's configure an
% unlimited number of triggers and use PEEKDATA to see what is happening.
ai.TriggerRepeat = inf;
start(ai);
pause(0.3);
pd1 = peekdata(ai,200);
pause(0.3);
pd2 = peekdata(ai,1000);
pause(0.3);
pd3 = peekdata(ai,2000);
%

%%
% Notice that the PEEKDATA function didn't block and that it returns only
% data that is available. We asked for 8000 samples but did not
% necessarily get that many.
whos pd1 pd2 pd3

%%
% This completes the introduction to analog input objects. Since the analog
% input object is no longer needed, you should:
%
% First stop the analog input object from running using the STOP command.
% Lastly, delete it with the DELETE command to free memory and other
% physical resources.
stop(ai);
delete(ai);
```

Data Analysis Code:

```matlab
clear
clc

fileName = 'xinxin speed4.txt';
col = 4 ;        %Col to work with
step= 1;    % my guess
```

```matlab
fr=500; % sampling rate HZ %%%%%%%%%%%%%%%%%%%% It is important
momemt!!!!!!!!!!!!!!!!
MeanStd = [];

if(ischar(fileName))
    [h,ddd]= hdrload(fileName);     %loads the data file
    % disp(' after eval load')
    ddd_copy(:,1)=ddd(:,2)*(-1);
    ddd_copy(:,2)=ddd(:,3)*(-1);
    ddd_copy(:,3)=ddd(:,4)*(-1);
    x = ddd_copy(:,col-1);
else
    x = fileName;
end


figure(1);    %plot raw data
plot(ddd(:,1),ddd_copy(:,1),'-b')
%title ('raw data');
%xlabel('time'); ylabel('V');
figure(2);    %plot raw data
plot(ddd(:,1),ddd_copy(:,2),'-r')
%title ('raw data');
%xlabel('time'); ylabel('V');
figure(3);    %plot raw data
hold on
plot(ddd(:,1),ddd_copy(:,3),'-g')
%title ('raw data');
%xlabel('time'); ylabel('V');
%figure(4);


t = 1:length(x);
num = round(length(x)/fr/step);
p1 = round(length(x)/num)
Peaks = [];
Time = [];

for(i = 0:(num-1))
  if(p1*(i+1) < length(x))
    p2 = p1*(i+1);
  else
    p2 = length(x);
  end
  int1 = x((p1*i+1):p2,1);
```

```
  time1 = t((p1*i+1):p2)/fr;
  peak1 = max(int1);

  peakpoint = time1(find(int1 == peak1));
  if(peakpoint > 1)
   peakpoint = peakpoint(1);
  end;
  Peaks = [Peaks;peak1(:)];
  Time = [Time;peakpoint(:)];
end

inter = Time(2:length(Peaks)) - Time(1:(length(Peaks)-1));
dl = length(Time) + (length(Peaks) - length(Time));

Data = zeros(length(dl),3);

Data(1:length(inter),1) = inter;
Data(1:dl,2) = Time(1:dl);
Data(1:dl,3) = Peaks(1:dl);
if(isstr(fileName))
name = [fileName(1:3),fileName((length(fileName) - 1):length(fileName)),'wal.dat']
if(exist(name))
 eval(['delete ',name])
end;
 eval(['diary ',name]);
end;
disp(Data);

diary off


MeanStd = [MeanStd;[mean(inter),std(inter);mean(Peaks),std(Peaks)]];
name1 = [fileName(1:3),'wl.msd'];
eval(['diary ',name1]);
disp('----------------------------------------------------------')
disp(' ');
disp(['File:      ',name]);
disp(' ');
disp('-----------------------------------')
disp(' BEFORE HEEL STRIKE      | Mean     | SD        |')
disp('-----------------------------------')
disp(['TIME INTERVAL:                     ',num2str(MeanStd(1,1)),'
',num2str(MeanStd(1,2))])
disp(['PEAK     (MAX):                    ',num2str(MeanStd(2,1)),'
',num2str(MeanStd(2,2))])
```

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```
disp('----------------------------------')
disp(' ');
diary off
clear fileName;

figure(4);
stem(Time(1:length(Peaks)),Peaks); %plot data as vert bars with circle on top
```

Appendix D

Experimental Data

Table D-1 The values of the peak points measured by MATLAB

Acceleration on left tibial tuberosity (g)	Acceleration on Forehead (g)	Acceleration on right tibial tuberosity (g)
2.20	0.659	4.93
3.27	0.650	5.52
3.47	0.523	4.93
3.76	0.484	4.44
3.18	0.532	3.57
4.84	0.503	3.96
4.35	0.542	4.15
4.54	0.620	3.66
5.03	0.298	3.57
3.76	0.347	3.76
5.42	0.454	3.66
4.25	0.474	7.57
3.37	0.562	6.79
3.67	0.474	7.18
5.32	0.806	2.20
4.05	0.620	6.40
3.47	0.474	3.86
4.15	0.816	5.32
4.15	0.611	4.84
3.08	0.669	5.81
3.47	0.513	5.71
3.57	0.493	2.49
4.93	0.474	6.59
	0.708	
	0.552	
	0.513	
	0.650	

	0.718	
	0.669	
	0.278	
	0.581	
	0.464	
	0.425	
	0.620	
	0.464	
	0.0537	
	0.386	
	0.103	
	0.542	
	0.532	
	0.542	
	0.689	
	0.679	
	0.698	
	0.611	
	0.640	

Table D-2 The data for forehead acceleration

Subject number	The acceleration on forehead at the speed of 0.894 m/s(g)	The acceleration on forehead at the speed of 1.341 m/s (g)	The acceleration on forehead at the speed of 1.788 m/s (g)	The acceleration on forehead at the speed of 2.24 m/s (g)
1			1.076	1.103
2			0.591	0.876
3		0.301		
4	0.318	0.455	0.634	1.222
5		0.364	0.588	
6		0.376	0.475	1.371
7	0.346	0.496	0.665	
8		0.222	0.509	1.038

	0.180	0.358		0.996
9	0.180	0.358		0.996
10	0.249	0.316	0.537	1.339
Average	0.273	0.361	0.633	1.135
Standard Deviation	0.0746	0.0867	0.186	0.183

Table D-3 Distance between the tibial tuberosity and forehead

Name	Age	Gender	Height(m)	Distance from forehead to the tibial tuberosity
1	24	F	167.64	1.199
2	20	F	162.56	1.162
3	21	F	154.94	1.108
4	20	F	162.56	1.162
5	20	F	160.02	1.144
6	21	M	190.5	1.362
7	20	M	175.26	1.253
8	22	M	170.18	1.217
9	21	M	182.88	1.308
10	21	M	182.88	1.308

Table D-4 The time of flight

Name	Time of flight at speed of 0.894m/s(s)	Time of flight at speed of 1.134m/s (s)	Time of flight at speed of 1.788m/s (s)	Time of flight at speed of 2.240m/s (s)
1	0.295	0.256	0.182	0.1598
2	0.235	0.257	0.1462	0.1658
3	0.305	0.248	0.1525	0.1622
4	0.236	0.259	0.1465	0.1650

Table D-5 The velocity of the shock wave

Name	Velocity at the speed of 0.894m/s (m/s)	Velocity at the speed of 1.134m/s (m/s)	Velocity at the speed of 1.788m/s (m/s)	Velocity at the speed of 2.240m/s (m/s)
1	4.06	4.68	6.59	7.50
2	4.94	4.52	7.95	7.23
3	3.63	4.47	7.27	6.83
4	4.92	4.49	7.93	7.04

My name is Yueyang Zhao. I got my B.Sc. in Energy and Power Engineering from Huazhong University of Sci. & Tech., China, in 2012 and M.Sc. in Mechanical Engineering from Lehigh University in 2015. My research interest area is heat transfer, fluid mechanics and Microfabrication.