Field Measurement of Running Impacts

Mid-Semester Paper

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Abstract

Dr. Bryan Heiderscheit is a physical therapist whose goal is to identify characteristics of running that lead to stress fractures. The purpose of this project is to create a portable system that records tibial acceleration data to measure the impacts of running. This device will include a lightweight accelerometer which will record data to a data logger. The acceleration data will be used to assess and treat running-related concerns. Three designs alternatives have been considered: a wired system, a wireless system, and a microcomputer. These designs were evaluated using a design matrix, which compared certain design criteria set forth by the client. The best design, the wired system, has been selected and a prototype of this design will be pursued. Future work entails purchasing a data logger and accelerometer, constructing the device, and testing the device to assure accurate data collection.

Problem Statement

The purpose of this project is to design a portable instrument that records tibial acceleration data to measure the impacts of running. The device should use a lightweight accelerometer, which will record data to an incorporated data logger. The device must be easily worn by the user and should not affect the performance of the runner. This instrument will be used to diagnose stress fractures and other injuries related to running.

Client Motivation

Our client, Dr. Heiderscheit, is a physical therapist who operates the UW Health Runners' Clinic. One of the goals of his clinic is to identify characteristics of running that lead to stress fractures. By adjusting how his patients run, Dr. Heiderscheit is able to prevent tibial stress fractures and other running-related injuries. Using acceleration data, he can analyze a patient's running habits to assess and treat running-related concerns.

Background Information

Stress fractures are one of the most common running injuries, accounting for 50 percent of all injuries in runners and military recruits (Milner 323). Between 33 and 55 percent of all stress fractures occur in the tibia (Milner 323). Tibial stress fractures may be caused by strong, repetitive stress on the bone at the insertion point of the muscles (Derrick 998). The bone absorbs the force of the impact instead of the muscles, and bending stresses in the tibia become too great for it to tolerate. In adults, tibial stress fractures usually occur in the anterior junction of the lower third of the bone, as shown in Figure 1.

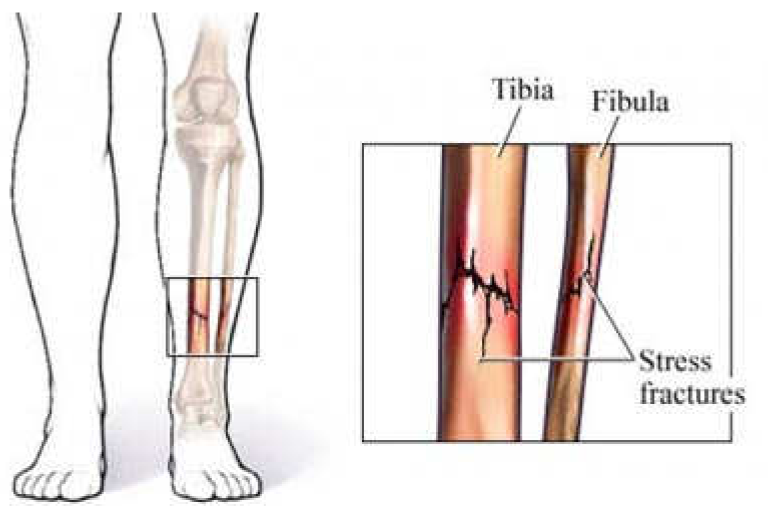

Figure 1: Anatomy of a typical stress fracture (Smith).

Correlations may exist between greater amounts of force on the tibia and the risk of obtaining a stress fracture. When the foot contacts the ground, the angle of the knee could have an effect on the severity of the impact (Derrick 836). Tibial stress fractures can be very painful, and can lead to three to six weeks of no activity and up to six to nine months of inability to compete. Therefore, it is very important to study the cause and prevention of tibial stress fractures.

Currently, Dr. Heiderscheit studies tibial stress fractures by analyzing tibial acceleration data. In the lab, patients run on a treadmill while wearing an accelerometer. The accelerometer is placed on the anterior of the tibia, a few inches above the ankle. This accelerometer is directly connected to a computer that records and analyzes the data. Dr. Heiderscheit studies the peak accelerations in the data in order to assess the greatest impact forces and relates these forces to running-related injuries.

Unfortunately, this current set-up is not optimal. A lack of space in the lab prevents runners from running on force plates. Also, because of the extensive wiring required to connect the current system, runner must run in the lab, and cannot run in a 'natural' environment. Because of these flaws, an alternate setup is desired.

Design Requirements

The most important element of our design is that the new system needs to be portable while still being capable of recording data reliably. It must incorporate a lightweight, uniaxial accelerometer, which has the ability to measure up to 40G peak acceleration. The accelerometer will be used in conjunction with a data logger to record measurements. The data logger must sample 1,000-2,000 Hz from multiple analog inputs. This design should not alter the runner's gait, performance, or speed in any way, and should be comfortable for the runner's use. Finally, the prototype should be completed for use in studies to be performed this summer. Refer to Appendix 1 for complete outline of design specification.

Preliminary Design Ideas

Design 1 – Wired system

The first design is a wired system that consists of an accelerometer and a data logger, both worn by the user. The data logger would be worn on a belt around the waist while the accelerometer would be attached to the leg by an adhesive. A wire running up the leg would connect the two components. The wire would also be attached to the leg to prevent it from being accidentally disconnected. A battery in the data logger would power both itself and the accelerometer, and the logger would have a memory card input allowing for data to be easily transferred between the logger and a PC. See Figure 2 for proposed design idea.

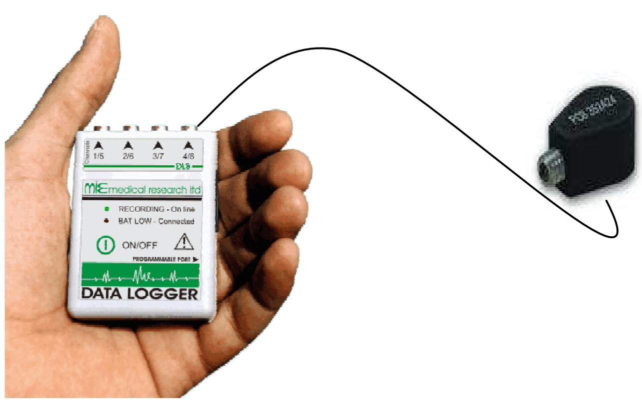

Figure 2: Data logger (MIE Medical Research Ltd) (left), wired to accelerometer (PCB Piezotronics) (right).

This proposed design has some obvious advantages. Since a wire connects the data logger and accelerometer, data can be reliably transferred between components in the system. Also, as noted earlier, the data logger would supply power to the accelerometer, so the accelerometer will not need its own battery. This greatly reduces the overall size and weight of the accelerometer and makes it less likely to affect the gait of the subject. A third advantage to this design option is the fact that this system would provide a good opportunity to evaluate the feasibility of a portable data logging system. Once this system has been tested and used for a period of time, it will be much easier to confirm that a portable system of this nature is indeed practical and accurate.

There are also some disadvantages to this system. One of the main problems is a potential to have wires accidentally disconnected or snagged, which may damage an input on the logger. To prevent these accidents from occurring, a leg sleeve could be developed to protect the wiring on the leg and ensure that the accelerometer is worn properly. A second disadvantage to this system is that the data logger must be worn on a belt around the waist, which may be bulky and uncomfortable. While it is doubtful that this belt would alter a runner's performance in any way, it may still cause some discomfort. Unfortunately, this is the best place to wear the data logger, so there is no better approach to fix this issue.

Design 2 – Wireless system

The second design is a wireless device consisting of two main components: a data logger worn on the waist and an accelerometer attached to the leg. See Figure 3 for the wireless accelerometer. The main difference between this system and the previous one is that the two components would communicate with one another wirelessly via Bluetooth technology. Each component would have its own battery supply. If a data logger with Bluetooth inputs cannot be found, an RS-232 converter would be needed to enable the logger's digital inputs to receive Bluetooth signals. An example of this converter is shown in Figure 3. The accelerometer would collect tibial accelerations and submit voltage data through a wireless radio channel to an input on the data logger.

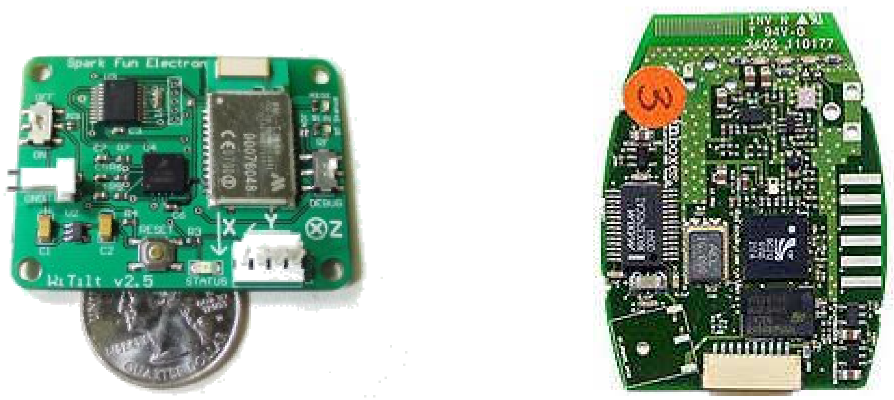

Figure 3: Bluetooth accelerometer at left (Spark Fun Electronics). RS-232 converter at right (Tek Gear).

The advantages of this design include increased comfort for the patient. No wires would be needed to connect the accelerometer to the data logger, and this will prevent snagging by the patient's arm or any other external obstacles while running. The development of this wireless device could also lead to a more compact system consisting of a PDA or watch device and a wireless accelerometer. These future developments would bypass the need to wear a data logger on the waist, increasing the comfort of the patient and creating a potential for a marketable product.

A disadvantage of this design is the potential for unreliability in the signal between the accelerometer and data logger. The patient will be running in a variety of environments surrounded with other signals that may interfere with the device, and this interference could result in incomplete or inaccurate data. In addition, the weight of the accelerometer would be increased relative to the previous design, due to the addition of its own battery supply. This could potentially alter the gait of the runner and contribute to inaccuracies of recorded data. The increased weight of the accelerometer may also cause it to detach from the tibia, which would result in inaccurate data. Additionally, this design requires more hardware and knowledge of technological interfacing of electronic devices, making it more difficult to manufacture. The data logger needs to be properly equipped with a Bluetooth input converter and configured to recognize the specific Bluetooth signal from the accelerometer. It is also uncertain whether or not all of the components would be compatible in this system. Finally, as with the previous design, the data logger might be cumbersome on the waist and decrease the comfort of the patient.

Design 3 – Microcomputer design

The third proposed design involves the use of a microcomputer to record data. This device would differ from the previously proposed designs because both the logger and accelerometer would be worn on the leg. This system would require the integration of all components on a circuit board, including an accelerometer, amplifier, analog-to-digital converter, and microcomputer. A diagram of this design is shown in Figure 4. The entire system would be powered by a single power source. The data measured by the accelerometer would be sent through the amplifier to an analog-to-digital converter. The data would then be stored in either the onboard memory or an external memory chip. Following a run, the microcomputer could be directly connected to a personal computer to analyze the data.

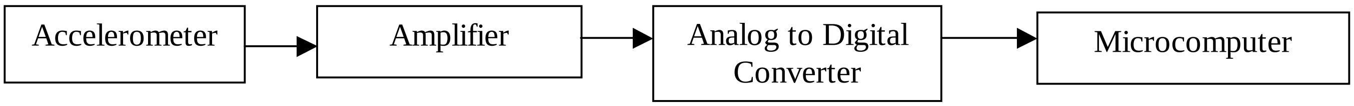

Figure 4: Schematic of the microcomputer circuit.

An advantage to this device is that all components are contained on one circuit board, making it very compact. A very reliable signal is ensured because all of the components are directly connected. Also, since there are no wires running along the leg, there is no potential for snagging. Finally, this device would be more comfortable for a user because no data logger would be worn on the waist.

The main disadvantage of using a microcomputer is the relative complexity of the design. Assembling the microcomputer would require advanced knowledge of circuits and because the device would have so many components, it would also take a long time to develop. Given the time constraints, the microcomputer design is not feasible for our project this semester. Also, it is unknown if this device would alter the runner's gait because the weight and measurements of the device could only be determined when the microcomputer is assembled. If the device is too large or too heavy, it might not stay secured to the tibia and could potentially alter acceleration data.

Design Matrix

	Wired	Wireless	Microcomputer
Signal Reliability (40)	10	7	10
Feasibility (30)	10	6	3
Lightweight on leg (20)	9	7	6
Comfort (10)	6	7	8
Total (100)	**94**	**61**	**69**

Figure 5: Design Matrix.

We picked the best design based on a weighted design matrix using four main criteria (Figure 5). The most important (and therefore highest weighted) criterion is signal reliability, since the device is useless if it cannot receive the signal from the accelerometer. A hardwire connection would provide the most reliable signal. The wired design received a ten in this category because there are wires directly connecting the accelerometer to the data logger. The microcomputer device also received a ten because the accelerometer and the data logger are directly connected in the circuit. The wireless design involves signal transmission via Bluetooth, which introduces the possibility of interference from other electronic devices. For this reason, the wireless design received a seven for signal reliability.

The second category we evaluated was the feasibility of completing the project within the client's desired time frame. Since our client plans on using this device in experiments this summer, it is important that we have a functional prototype by the end of the semester. The most feasible design was the wired system, since we have been able to find all of the parts we would need to construct the device. The wireless design is less feasible, receiving a seven in this category. This score is based on the fact that we cannot find a data logger with wireless inputs, and any adapters we have found would involve altering the hardware of the data logger or using bulky adapters. The microcomputer design is the least feasible because we do not believe it would be possible to finish this design over the course of the semester.

The third consideration in the design matrix focused on how much weight will be added to the leg. It is important to minimize the weight worn on the leg since excessive weight will alter the stride of the runner and result in data inconsistent with the runner's normal stride. The wired design is the most lightweight because only the accelerometer is worn on the leg, and therefore received a nine. The wireless design scored a seven because an additional power supply must be worn on the leg. Finally, the microcomputer device is the heaviest because everything is worn on the leg.

The final category we judged was the comfort of the device. The wired design received a six since the data logger must be worn on the waist, which could be bothersome. Additionally, the wires running down the leg to the accelerometer could snag or otherwise alter the runner's gait. However, we believe that by securing the wires to the runner's leg, this factor can be minimized. The wireless design received a seven because it does not have the same problem with wires, but does still require a data logger to be worn on the waist. The microcomputer received the highest score in this category because everything is worn on the leg, so it requires no wires. Also, the device is relatively lightweight and therefore minimizes discomfort. However, since there is added weight to the tibia that the runner normally would not have, it only received an eight in this category.

After weighting the scores and computing the totals, the wired device came out ahead of the other two designs. This is mainly due to its high signal quality and the likelihood being completed within the desired time frame. Therefore, we plan on pursuing this design for the remainder of the semester.

Future Work

By the end of the semester, our goal is to have a functional prototype that can be used for field measurements this summer. In order to accomplish this goal, we must finalize the purchase of the data logger, which includes contacting the manufacturer to inquire about interfacing the accelerometer. We also need to choose an accelerometer, and order all of the components by the end of March. While the parts are being shipped, we will concentrate on designing a system that will firmly attach the unit to the runner. We will focus on how to best adhere the accelerometer to the tibia and ensure that the wires cannot be snagged.

Following this schedule, the team will be left ample time to construct and test the device. Once the device has been assembled, we will make any necessary software adjustments to ensure the compatibility of the device before continuing with testing. Through testing, the team will then be given a chance to fix any unforeseen problems with the prototype. We will also evaluate the quality of our data by running with the existing equipment and our device simultaneously. This type of testing will confirm or deny the validity of using a portable system to measure forces on the tibia. If the portable system proves to be reliable, future possibilities will exist to refine the prototype and develop a microcomputer design.

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-Appendix 1-

Running Impacts Product Design Specification (PDS)*

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3/14/07

Function: The completed prototype will measure the impacts of running using tibial acceleration data. The device should use accelerometers, which will record data to an incorporated data logger. The device must be easily worn by the user, and the hardware should have the ability to do most of the data processing. This instrument will be used to diagnose stress fractures and other injuries related to running.

Client requirements:

- $1500 budget excluding data logger
- Durability and battery life are important for field use
- Continuous, solid, reliable signals are required
- Ensure that the accelerometer does not move with respect to the tibia
- Data should be processed either by the data logger or software
- Unilateral tibial acceleration measurements will suffice for the first prototype

Design requirements:

1. Physical and Operational Characteristics

a. *Performance requirements*: Ideally, the runner will take the device into the field and record data from three runs. The battery life and memory must be able to accommodate this criterion.

b. *Safety*: The equipment and wiring needs to be secured to the runner.

c. *Accuracy and Reliability*: Data logger should record data at a sampling rate of 1-2 kHz. The accelerometer should be able to record peaks of 40G's, although it should have good resolution for the 0-20G range since this is the normal range.

d. *Shelf Life*: Device should be able to be powered off when not being used to save power.

e. *Operating Environment*: The device will be used primarily outdoors. Therefore, the device must be able to withstand variations in temperature and other weather elements like wind and humidity. The device may be exposed to considerable dirt and dust from the atmosphere. The device will be moving up and down with the runner, so all connections should be secure.

f. *Ergonomics*: Any device pieces that are worn on the leg should be placed on the outside or back of the leg to prevent damage due to running style. The wiring should not interfere with the runner's strides.

g. *Size*: Everything must be able to be worn while running.

h. *Weight*: The unit should be as lightweight as possible to maximize comfort. The portion of the device that is worn on the tibia must be especially light so that it does not interfere with the runner's gait.

i. *Materials:* The device must be attached to the runner's tibia using a material that will conform to the leg's shape either by wrapping or using a relatively elastic material.

j. *Additional Client Preferences*: A wireless system (possibly Bluetooth) would be preferred, but may not be practical for a first prototype. Also, if possible, the data logger should process and only store data points that are above a certain threshold.

2. Production Characteristics

a. *Quantity*: One.

b. *Target Product Cost*: The budget for the product is $1500, excluding the cost of the data logger.

3. Miscellaneous

a. *User*: The device should be comfortable to wear when running (for example, the device doesn't bounce when running).

b. *Patient-related concerns*: The device must be able to be wiped with a disinfectant between patients.

c. *Competition*: Current set-ups are stationary, so the patient must come to the lab to partake in the study. The impacts cannot be measured over the runner's normal paths. No portable devices can be found on the market.