Comparison of Force and Flexibility in Gait Analysis of Sunnystep and New Balance Shoes

by

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Abstract

0.1 Abstract

The goal of this paper is to discern if there exist any differences in forces, acceleration, and muscle stiffness when wearing different pairs of footwear. The first pair of shoes tested were New Balance shoes and the second were Sunnystep shoes. From the data, it was shown that on average the body experiences more force when wearing the Sunnystep shoes. The data also demonstrated that the feet had higher acceleration during walking in the Sunnystep shoes than the New Balance shoes, meaning more "stomping" was occurring and thus more impact on the joints. Finally, the Sunnystep shoes had significant effects in decreasing calf stiffness but did not appear to affect hip stiffness. Overall, the Sunnystep shoes were worse for the joints but better for the muscle flexibility.

Thesis Supervisor: Peko Hosoi
Title: Associate Professor of Mechanical Engineering

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Chapter 1

Introduction

Sunnystep is a shoe company whose founder, Mao Ting, suffered from a traumatic spine injury that seriously compromised her mobility. Ting needed comfortable walking shoes that minimized stress for the feet and the body, so she founded Sunnystep with that goal in mind. As a Division III collegiate lacrosse player who has suffered three ACL injuries, the most recent from which I am still in the rehabilitation process, the mission of Sunnystep resonated strongly with me. Performing the tests outlined in this thesis on myself aligns well with Sunnystep's goal to minimizing stress for injuries. The objective of this paper is to conduct different experimental tests in order to see if we can discern a difference between Sunnystep footwear and other footwear and the effects they have on the body of the wearer. Three different tests were run to explore the differences in these shoes. First, a test designed to look at the forces felt by the feet when walking in the shoes. Second, a test intended to look at acceleration of the feet when walking to visualize walking patterns. Finally, flexibility tests to determine how the shoes affect both muscular flexibility in both the calf and the hip.

Chapter 2

Force

A commonly accepted fact in the footwear industry is that increasing the padding in shoes helps buffer the forces felt by our bodies, while simultaneously increasing overall comfort. Many healthcare professionals encourage consumers to select shoes with high levels of padding, claiming it will "reduce the impact forces on the body's joints and tissues during weight-bearing activity" [1]. However, this is not always the case. Excessive padding can actually have the opposite effect, leading to increased forces on the body. More padding means that the human body has limited sensation when it comes to how the foot and ground are interacting. With less padding, the mechanoreceptors in the foot have a more accurate representation of the connection between the ground and foot, tending to create "gentler and more mindful" steps [1]. With padding, the foot senses a reduced impact, allowing "sloppy" steps that consist of heavy foot slaps, the full impact of which the body does not register. That is not to say the impact does not affect the bones and muscles, but merely that the sensory system is more numb to it, and therefore does not warn the body against this harmful behavior. From a force-body diagram on one foot, the following equation is produced:

$$\text{N - mg} = \text{ma}$$

Then, inserting in for acceleration and solving for normal force, the equation becomes:

$$\text{N} = \text{m((vf - vi)t+g)}$$

Excessive padding shifts the human gait, increasing the velocity up and down from the ground, and thus ultimately increasing the normal force that the body experiences.

To test the force on the feet when walking, force sensing resistors (FSRs) were placed inside the shoe where the heel of the foot lands. FSRs are variable resistors with resistance that depends on force. These force pads are used with an operational amplifier circuit, which provides a linear relationship between force and voltage.

Figure 2-1: FSR attached to the heel of the shoe.

In each trial, one minute of walking data was recorded. Because the FSR outputs potential and not force, the FSRs had to first be calibrated on a force plate in order to find the function relationship between voltage and force; a power function was the best fit for this specific dataset, as shown in Figure 2.2. Using this relationship, the potential data was converted into force data for each foot.

One trial was conducted each day for five consecutive days in the New Balance shoes, and then the experiment was repeated for the Sunnystep shoes.

For each day, all of the steps that were taken in the minute duration were overlaid, and an average force function for a singular step on that day was found. Figure 2.3 shows an example of this, using the data for the left foot in the SunnyStep shoes on

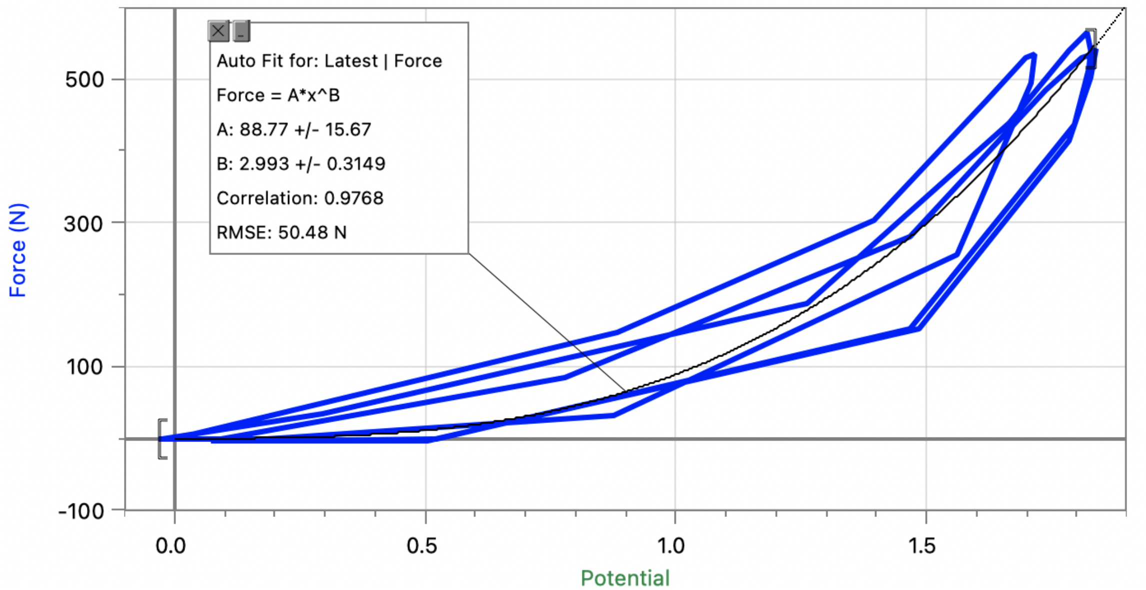

Figure 2-2: The fitted correlation relationship between Force (N) and Potential (V). The result is a power fit of $y = 88.77 * (x)^(2.993)$.

the fourth day. This first graph in Figure 2.3 shows the raw force versus time data. To create the second graph, the average force from the raw data was calculated. That line was then plotted. From this, each time the average force line intersected the raw data, it was collected and used to cut the data into distinct steps. Once each step was isolated, they were overlaid. The final graph is the average of all the steps. This was achieved by taking averages of all the steps at each of the five timestamps shown as vertical lines on the second graph.

The same data analysis was performed for each foot for five days in both the New Balance and the Sunnystep shoes, and the graphs can be seen below in Figure 2.4.

From these graphs it can be seen that, with the exception of the left foot on days 3 and 5, the forces felt during steps are higher in the Sunnystep shoes. Figure 2.5 demonstrates that over the five day period the force experienced by the body was higher when wearing the Sunnystep shoes than when wearing the New Balance shoes. During the first two days, the forces felt when wearing the Sunnystep shoes were significantly higher than that of the New Balance shoes. However, this is likely due to the adjustment period the body needs when starting out with a brand new

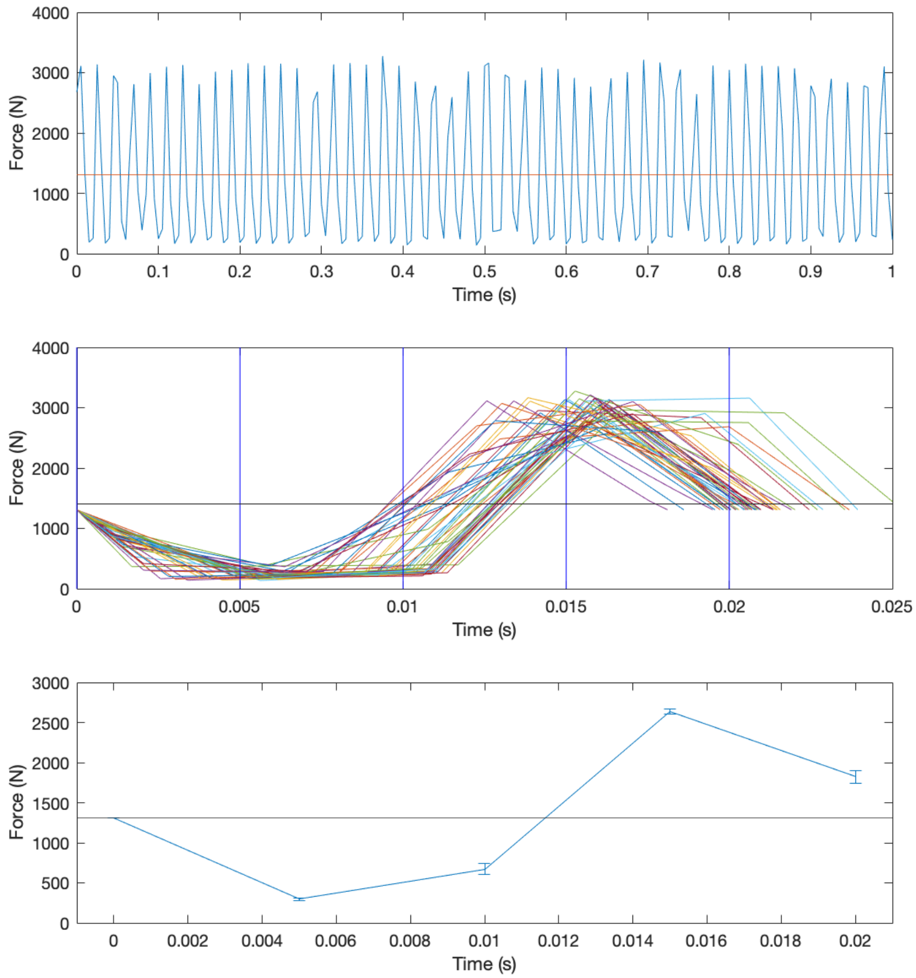

Figure 2-3: Data collected and analyzed for day 2 in SunnyStep shoes. Shows graphs of raw force data, overlaid steps onto one graph, and an average step for that day.

pairs of sneakers. It makes sense that the forces would be higher and the steps more like "stomps" while the body acclimatizes to the new shoes. The Sunnystep shoes have more cushioning than the New Balance shoes, due to both the design of the Sunnystep shoes as well as their relative newness when compared to the more worn-in New Balance shoes. Thus, the higher forces felt during the Sunnystep shoes could be do to the higher amount of cushioning, which as mentioned before may have opposite the desired effect and cause higher forces for the body. However, another explanation is that because the Sunnystep shoes are brand new and the New Balance ones are older, a week of wearing the brand new shoes was not enough time for the body to

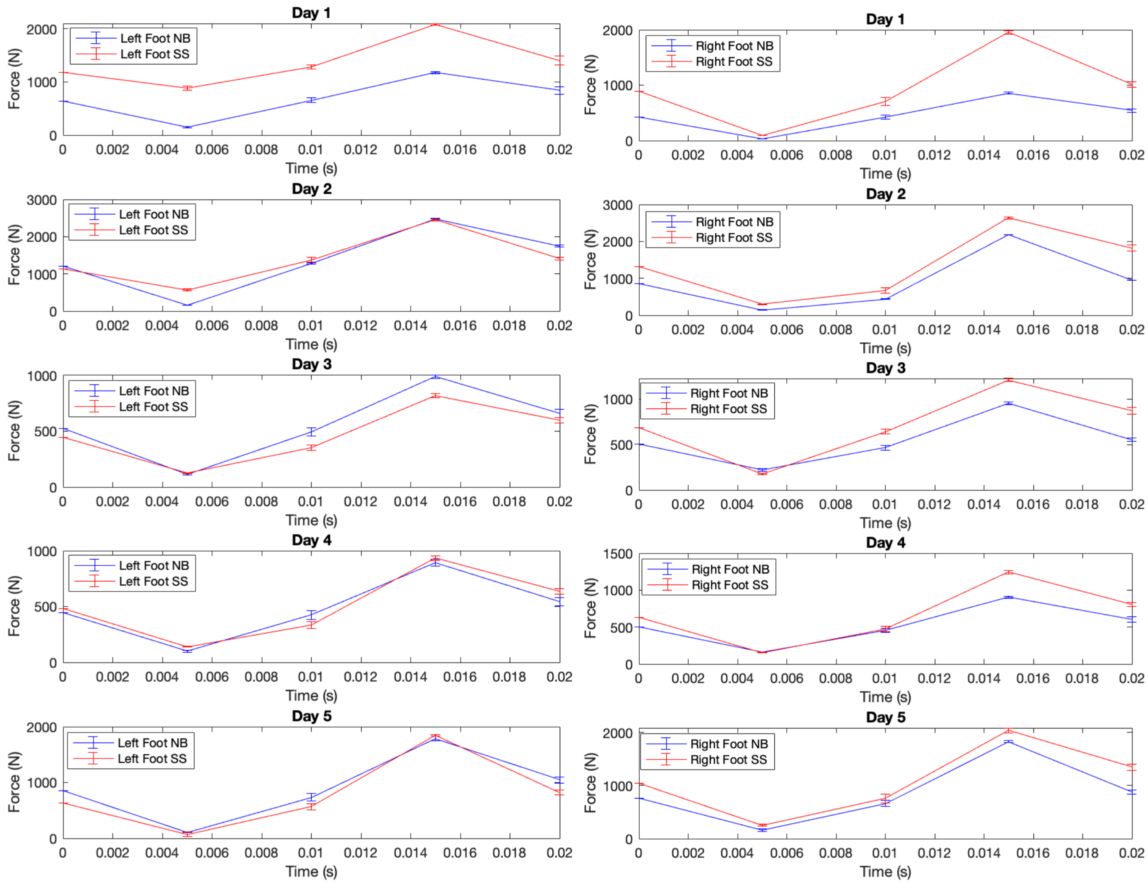

Figure 2-4: Graphs for an average step on the left and right foot for each day, comparing a step with the New Balance shoes and the Sunnystep shoes.

appropriately adjust to the new shoes, and if the Sunnystep shoes were worn for a longer period of time, we may have seen a decrease in force over time. A summary of the total number of steps taken for each day in both shoes in shown below in Table 2.1.

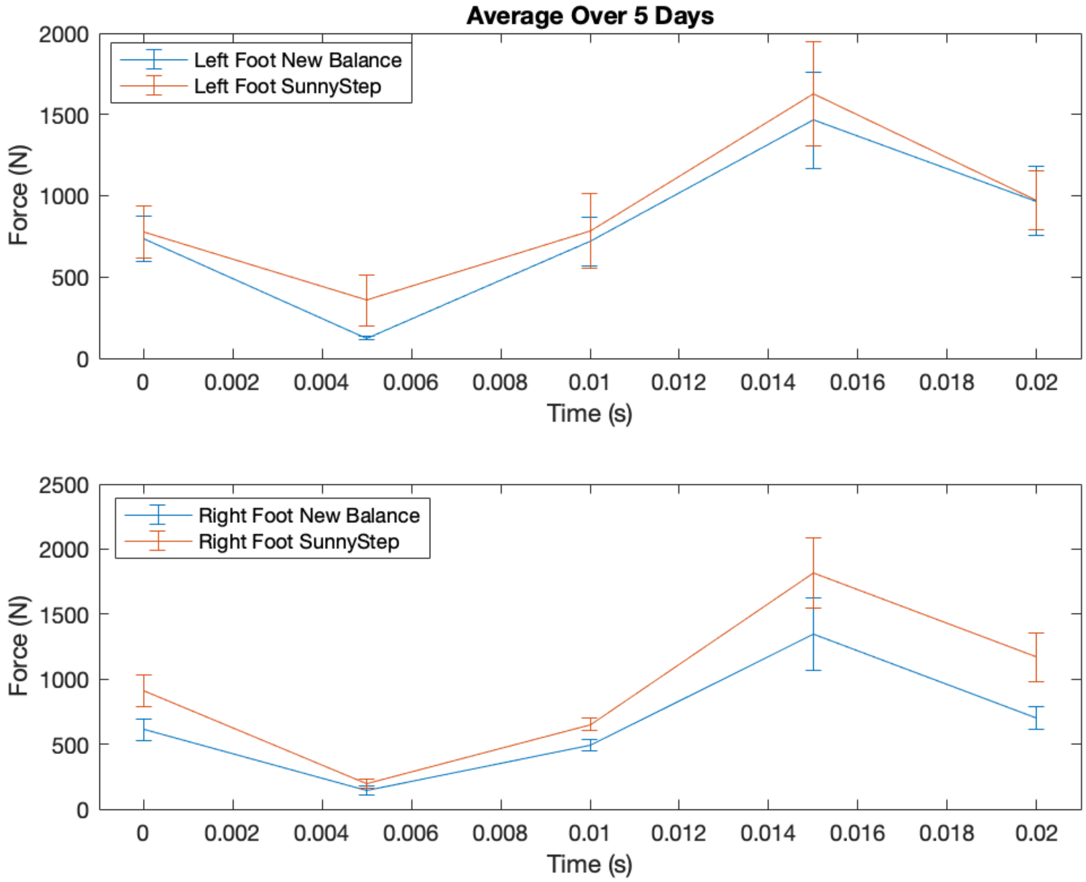

Figure 2-5: Graphs comparing forces in an average step over 5 days for both the New Balance and Sunnystep shoes.

	Sunnystep	**New Balance**
DAY 1	10,457 Steps	9,876 Steps
DAY 2	11,854 Steps	12,923 Steps
DAY 3	10,683 Steps	10,692 Steps
DAY 4	11,793 Steps	10,890 Steps
DAY 5	12,883 Steps	11,230 Steps

Table 2.1: Table showing total number of step taken each day for Sunnystep and New Balance shoes.

Chapter 3

Acceleration

To get an accurate visualization of gait when walking, a Vernier 25-g accelerometer was used. This allowed for an understanding of how acceleration and velocities changed when wearing the different shoes. As previously mentioned, when too much padding is added, the gait changes and the acceleration and thus force is increased. For the experiments, an accelerometer was taped to each ankle and once again collected data for one minute of walking. The same five day trial per shoe was used.

Figure 3-1: Accelerometer taped to the ankle and a line was drawn to ensure it was placed in the same spot for each trial.

Similar to the analysis conducted with the force sensing resistors, each step was overlaid and an average step for each day was created. Figure 3.2 shows the raw data, overlaid data, and an average step of acceleration values for one day, while Figure 3.3 shows the average steps across all five days.

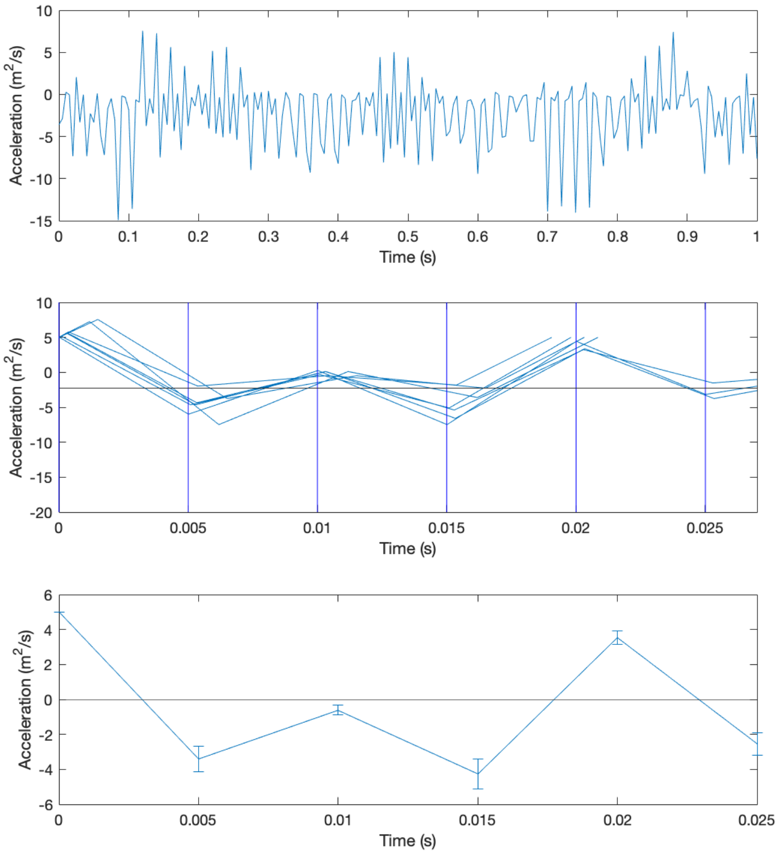

Figure 3-2: Data collected and analyzed for day 5 in Sunnystep shoes. Shows the graphs of raw force data, overlaid steps onto on graph, and an average step for that day.

Figure 3.3 shows that for each of the five days on both feet, the Sunnystep shoes tend to have higher accelerations. All five days in the New Balance shoes have a fairly consistent shape. However, in the first few days with the Sunnystep shoes the shape is much different, showing that the gait has changed slightly. By the fourth and fifth day, the gait begins to more closely resemble the New Balance gait. This corroborates the idea that the body takes time to acclimate to new shoes. Figure 3.4 demonstrates that in looking at the average over five days, the accelerations are larger on the Sunnystep shoes. This is consistent with the findings from force, as Newton's Second Law states that force and acceleration are directly proportional (F = ma). Thus it makes sense that accelerations are higher for the Sunnnystep shoes, as it was found that the forces were higher as well.

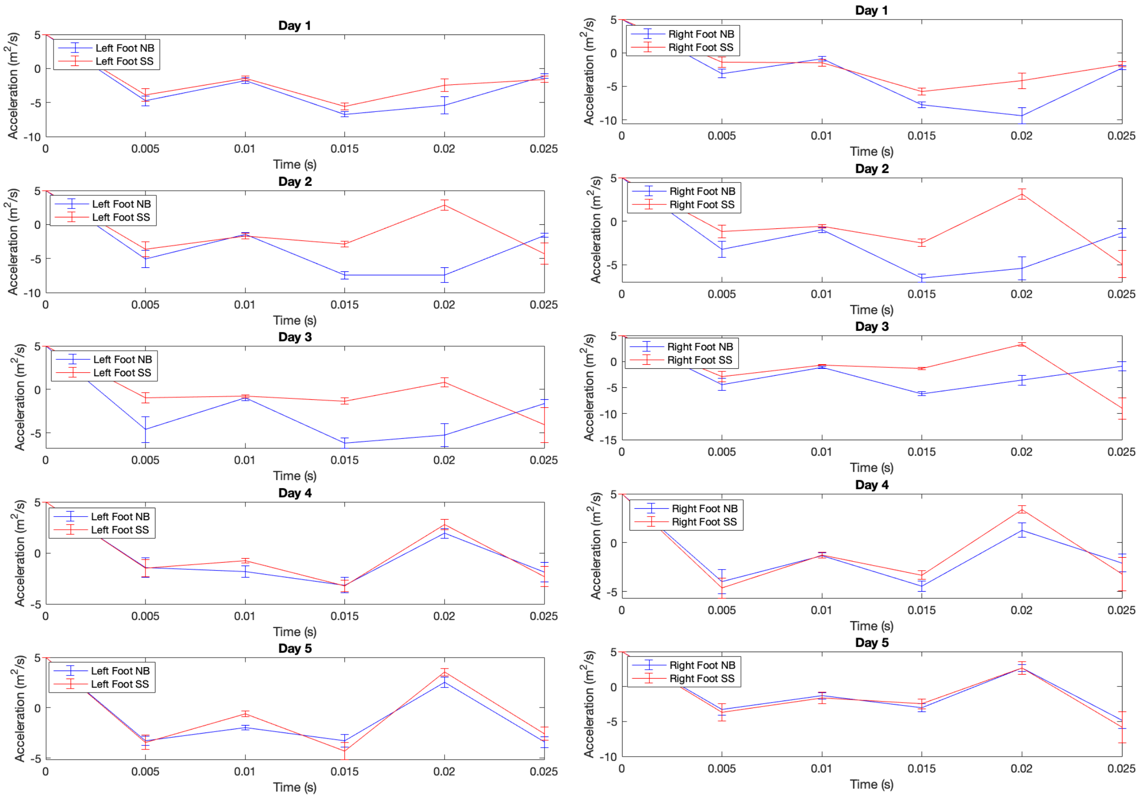

Figure 3-3: Graphs for an average step on the left and right foot for each day, comparing a step with the New Balance shoes and the Sunnystep shoes.

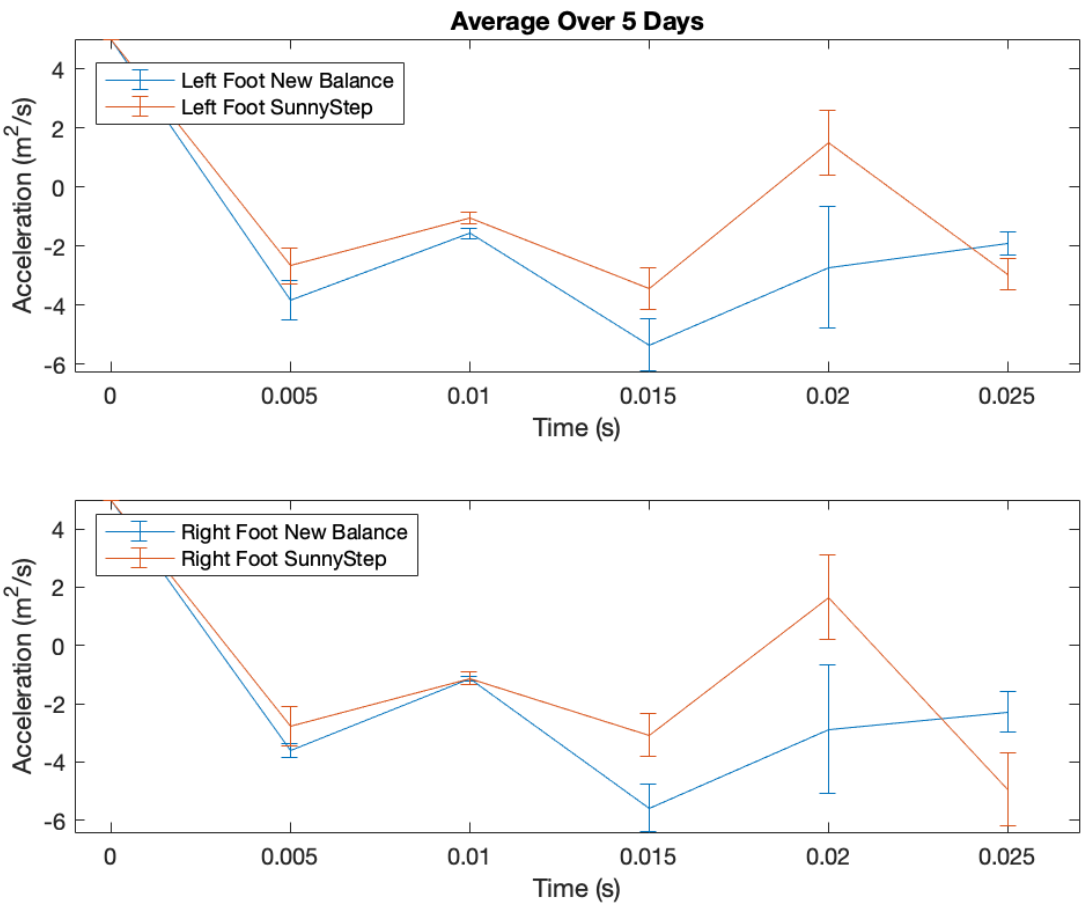

Figure 3-4: Graphs comparing acceleration in an average step over 5 days for both the New Balance and Sunnystep shoes.

Chapter 4

Stiffness and Flexibility

The final experiment was intended to determine if the different shoes had any affect on flexibility in the lower extremities. Shoe design can definitely have an impact on calf stiffness and cause pain. The drop of a shoe, which is the difference between heel and midfoot height, can affect the calf. Even lowering the drop from 2mm to 8mm is “enough to be a cause of all kinds of issues in your calves” [2]. Each pair of shoes were worn for a full week, during which the subject underwent flexibility measurement tests with an MIT Athletic Trainer. On four days in each week, the trainer performed three tests that measured calf flexibility and one that measured hip flexibility. Figure 4.1 shows the four tests being performed. The first test the trainer performed measures the calf movement in degrees while the leg is straight. The second test is when the leg is bent at 90 degrees. Then the third test measures calf flexibility by looking at the forward distance the knee is able to bend without lifting the heel off of the ground. The fourth test measures range of motion and hip flexibility.

From the data, shown below in the graphs in Figure 4.2, the Sunnystep shoes cause increase in flexibility and decrease in stiffness through each of the three calf measurements. Taking an average over all the four days of testing, we see below that the averages of degree of left and right legs for all calf tests increase for Sunnystep. However, from that data it appears the Sunnystep shoes slightly decrease hip mobility. However, further experimentation would be required before drawing a definitive

Figure 4-1: The four tests performed for calf and hip flexibility.

solution about these shoes and their effects on flexibility, as these measurements were done by eye and are susceptible to human error.

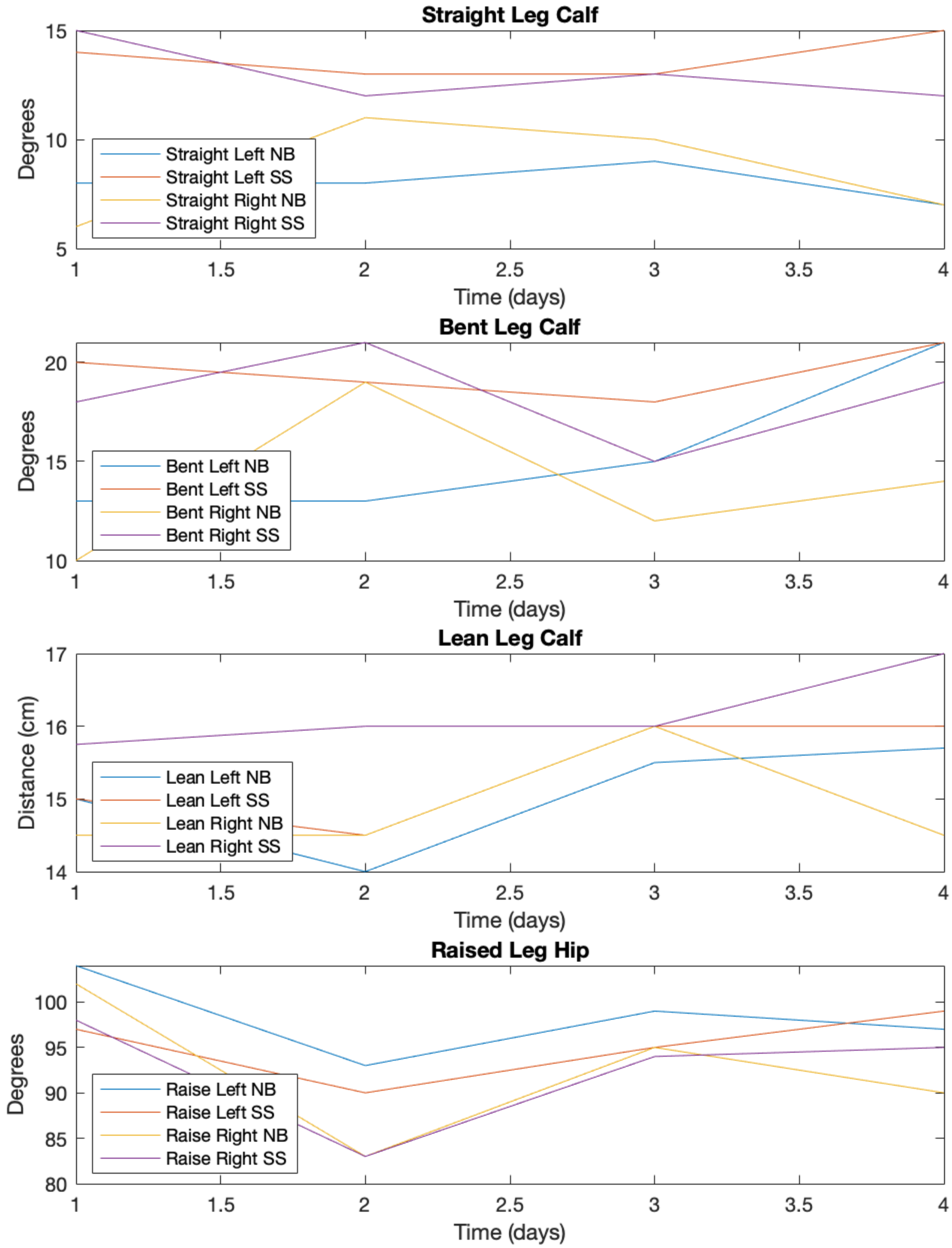

Figure 4-2: Graphs displaying four different tests for muscle stiffness over a four day period.

Chapter 5

Conclusion

From the data collected across the first experiment, the Sunnystep shoes resulted in the body experiencing higher forces than those felt when wearing the New Balance shoes. The accelerations analysed in the second experiment were also higher, which is in alignment with the conclusions drawn from the first. The Sunnystep shoes had more padding and were more new, and so the hypothesis that more padding can contribute to greater impact was confirmed. For both accelerations and force, the differences between the two shoes were much greater in the first few days but by the fourth and fifth day were almost identical. This makes sense as the body needs time to adjust to different shoes. Additionally, the Sunnystep shoes had a large effect on calf stiffness; it was measured that they significantly increased calf flexibility when compared to the effect of New Balance shoes on the body. The Sunnystep shoes forced an alteration of the body's gait that resulted in higher forces, but also reduced stiffness in the calf. Recommended future work would be to test test both pairs of shoes after wearing them for a longer period of time. One next step would be getting new Sunnystep shoes as well as new New Balance shoes and wearing them both for about 2 months before beginning testing. This way there is no disparity in shoe life and the body has time to adjust to the shoe properly beofre testing begins, allowing for the most accurate results.

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