Dev Lochan, CVHS 11th Grade
Year 5

Taking Another Step Towards Solving the Foot Crisis: Reducing Joint Impact with Magnetic Levitation | Year 2

Engineering Goal

And Rationale

Problem:

To create a **cheap, soft, and light** shoe sole using magnetic levitation, improving on the project from last year

Rationale/Need:

Foot pain has become a major issue among humans as a population. My mom has recently developed Plantar Fasciitis, which puts her in an immense amount of discomfort at points, discomfort that current shoes can't help enough. To address this growing problem, the shoe sole needs to be reinvented and this magnetic levitation is the answer to people's problems

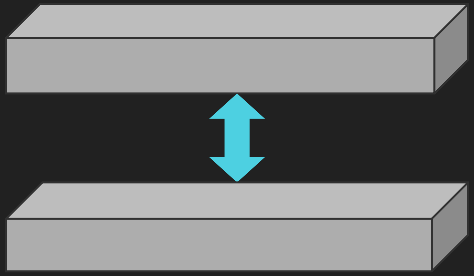
Testing and Constraints:

Constraints include a budget of **$20, 320.35 g of total weight**, and **access to regular machines** available in a common workshop.

These constraints **ensure that the shoe remains practical enough for everyday wearing**. The budget makes sure that the shoe won't cost too much more and the weight limits the amount of extra weight that can be added on, which could greatly reduce the practicality.

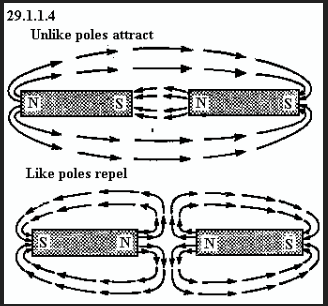
Solution

The proposed method is a Halbach Array based magnetic levitation system embedded in the sole of the shoe to further reduce the footsteps' impact force, which therefore reduces the force exerted on joints as well. By using magnetic levitation, the force is spread out across the fields which absorb the impact shock of the footstep much better than foam could. Because magnets push more when they have more force on them, they can adapt to the situation they are put under, not to mention the greater durability when compared to current shoes. This makes it **many times more practical** than the previous shoe.



Research and Concept Review

Magnetic Principles



http://www.lewpaxtonprice.us/magnet.htm

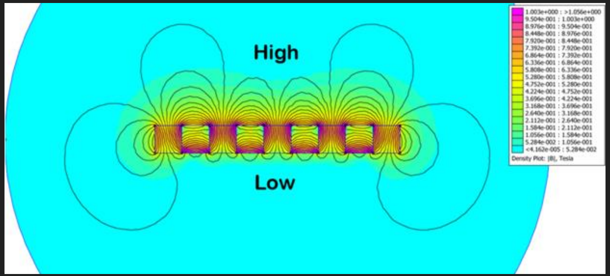
Law of Magnetism: Opposite poles attract each other and similar poles repel

Basis of magnetic suspension: repulsive properties

- Magnetic Repulsion will provide a contactless suspended feeling for **less impact**, and therefore less shoe midsole compression
- Magnets exert **exponentially** increasing force as force is applied to them

Halbach Arrays: A magnet formation that reduces flux across one face and moves it to the other face

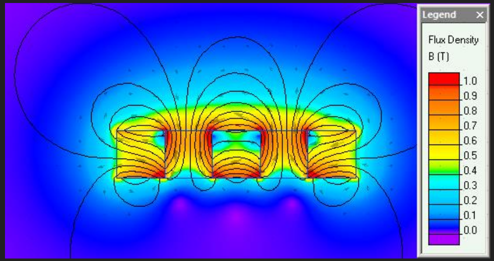
- A way to lift the entire force of a person with just a few magnets



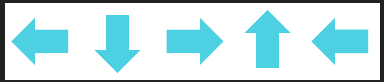
https://www.magnet-sdm.com/2018/10/30/halbach-array/

Research and Concept Review

Halbach Arrays



https://quickfield.com/advanced/halbach_array.htm



Advantages

- The most obvious benefit of a Halbach-style Array is that the field produced is very strong when compared to other arrays having the same amount of the magnet alloy. The arrangement essentially increases the efficiency of the magnetic circuit.
- The by-product of the design is that there is only one working surface or “working face.” The one working-face, where the magnetic field resides, is very strong; and the non-working face has essentially no field. In essence, the magnetic field, which would normally be present on the non-working face, is rerouted to the working-face. This is true for both Circular and Planar style Arrays.

Disadvantages

- The primary disadvantage of the Halbach Array geometry is that it is difficult to put together, resulting in potentially higher manufacturing costs than other potential solutions. This is because all of the magnet elements are repelling each other in a Halbach Array. This can create a variety of assembly issues including: needing to assemble the magnets magnetized, combating the forces during assembly, and ensuring the assembly will “hold together” during its use.
- Another disadvantage is that Halbach Arrays may have an issue in high heat applications because the array elements apply a demagnetizing field on each other. As the operating temperature increases, a magnet is more susceptible to demagnetizing, and the neighboring magnet demagnetization is exacerbated.

Research and Concept Review

Medical Effects

Doctors Opinion: An orthopedic doctor was reached out to and asked for their opinion

- Main Points
  - Magnets have no proven medical effects on the body
  - Could be effective in distributing weight effectively
  - This is a new take on impact absorption with less space used, but more effective

Medical Studies: A study from 2008 about the effect of magnets on the body

- Main Points
  - No effects were found that show any kind of effect
  - An unverified idea states that magnets can increase circulation due to the hemoglobin in blood cells

Tools and Instruments

Provided by the school

- 1 Arduino Uno
- 1 Mx2125 Accelerometer
- 1 Breadboard
- 1 Medical Crutch
- Assortment of wires
- 30 x 30 x .3 cm Rubber Sheet
- X-Acto/Utility Blade
- Sharpie

Cost: $0 (graciously provided by the school)

Materials

Along with professional supervision

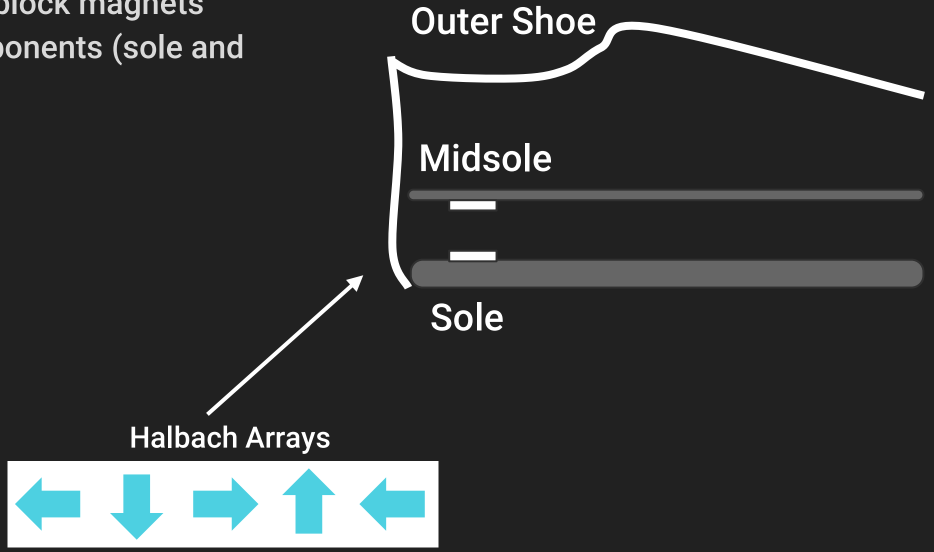
- 1 pair of men’s size 10 shoes
- 2 black zip ties
- 30.5 x 76 x .25 cm rubber sheet
- 40, 2.5 x .32 x .32 cm Magnetic Blocks
- 60, 1.9 x .32 x .32 cm Magnetic Blocks
- 2, 3.18 x 20.3 cm steel plate
- Aluminum Foil
- 2-Part Epoxy

Cost: $13 (under budget constraint of $20)

Designing and Concept Sketches

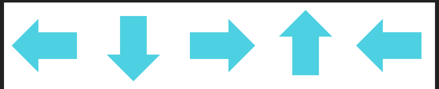
Plan for construction

- Utilize the engineering lab to **create a small working prototype** with an old pair of sneakers
- The Halbach Array would be made out of several small block magnets
- The magnets can be placed directly onto the shoe components (sole and midsole) for simplicity
- Epoxy was used to join the midsole onto the sole
    - **Total time taken: 6 weeks**



Building a Halbach Array

1. Wrap Steel Plates in Aluminum Foil
2. Mark same face on each edge of magnet with Sharpie
3. Place magnets on one steel plate in the configuration shown
4. Apply epoxy between each magnet
5. Place the second steel place on the other side of the magnets
6. Use a straight edge to sandwich the magnets together in the plates
7. Allow epoxy to cure for 24 hours before removing from plates



Prototype X Construction Procedures

Shoe Preparation

1. Remove the midsole and upper shoe body from the shoe to reveal the sole
2. Find the locations the magnets based on the model created and mark their locations with a sharpie
3. Cut the outline of the markings with an utility knife with a depth of 0.8 cm
4. Bore out the outline with a utility knife for all the outlines to a depth of 0.8 cm

Magnetic Fixture

1. Place the Halbach Arrays loosely on top of their holes with 2-part epoxy resin on the top
2. Align the midsole onto the its original position in the shoe and place the Halbach Arrays on the other side of the midsole to act as a “clamp” to keep the them in their intended positions during gluing
3. Let the epoxy dry
4. Place the corresponding Halbach Arrays with matching polarities facing each other on one side and firmly push it into their holes

Final Assembly

1. Cover the exposed shoe bed with a thin layer of epoxy
2. Carefully align the midsole onto the marks made earlier and resist the magnetic repulsion as much as possible to ensure complete alignment
3. Press down on the midsole to ensure the seal and allow 24 hours to cure

Issues/ Redesigning

With Prototype X

- The foam makes for a **thick and heavy** shoe
    - If the form is no longer needed for cushioning, it merely serves as **dead weight**. A better option is to make my own shoe sole from scratch that follows what I need
        - This may be a tougher option but it seems like the right way to go in order to **save weight, cost, and simplicity**
        - Options are making my own lightweight polyurethane foam or using a thin and durable sheet of rubber

Prototype Y Construction Procedures

Shoe Preparation

1. Trace and cut out 2 sole patterns of shoe on rubber sheet, one being bigger with an excess margin of 5 mm

Magnetic Fixtures

1. Find the locations the magnets based on the model created (from the prior year) and mark their locations with a sharpie
2. Glue Halbach Arrays, all with the same polarity, onto the positions marked
3. Repeat the same step on the other sole pattern

Final Assembly

1. Place the smaller sole pattern with the magnets facing up on the table
2. Apply a layer of epoxy in the areas around the magnets except within a radius of 1 cm and the rest of the exposed shoebed
3. Place the edges of the larger sole pattern on the edges of the smaller one and match the edges up
4. Press on the other areas around the magnets
5. Hold them together for 5 minutes to allow the bond to form

Testing

1. A microcontroller was wired to a small accelerometer to measure deceleration
2. A crutch was modified so that the hand grip was replaced with a metal rod that could hold the required barbell weights for testing and the rubber on the bottom leg was removed to simulate a more accurate barefoot-style test
3. To measure force across the entire foot, a 26.7 cm x 8.9 cm x 3.8 cm wooden block was cut to produce a certain percentage of the pressure based on the surface area. The purpose of this was to spread the force of the weights across the entire shoe. The data used came from a study which measured pressure across the foot. The surface area was calculated to be proportional to the pressure the area takes.
4. The bottom of the block was the chiseled to conform to the surface of the shoe, while maintaining the distinction in area created instep 3.
5. 32 kg (average weight of a leg) was dropped from a height of 2 cm (average height of a footstep) 30 times each on the unmodified shoe, a shoe with memory foam, and a modified shoe with memory foam.
6. Steps 3-5 were repeated to complete the running aspect of testing

Arduino Code

Used with Arduino IDE

```
const int xP = 11;
const int yP = 12;

void setup() {
  // put your setup code here, to run once:
  Serial.begin(9600);

  pinMode(xP, INPUT);
  pinMode(yP, INPUT);

}

void loop() {
  // put your main code here, to run
repeatedly:
  int px, py;
  int ax, ay;

  px = pulseIn(xP, HIGH);
  py = pulseIn(yP, HIGH);

  ax = ((px / 10) - 500) * 8;
  ay = ((py / 10) - 500) * 8;

  Serial.print(ax);
  Serial.print("\t");
  Serial.print(ay);
  Serial.println();

  delay(100);

}
```

Results

Table 1: Raw data table for the change in deceleration

	Walking		Running	
	Original Magnetic Levitation Shoe	Improved Halbach Array Shoe	Original Magnetic Levitation Shoe	Improved Halbach Array Shoe
Trial 1	6.05	5.64	7.6	6.91
Trial 2	6.32	5.67	7.68	7.04
Trial 3	6.35	5.66	7.31	7.08
Trial 4	6.22	5.51	7.41	6.92
Trial 5	6.12	5.73	7.66	6.87
Trial 6	6.16	5.66	7.3	6.94
Trial 7	6.31	5.64	7.53	6.76
Trial 8	6.06	5.48	7.71	6.78
Trial 9	6.09	5.51	7.39	7.07
Trial 10	6.2	5.46	7.69	6.9
Trial 11	6.03	5.5	7.62	7.03
Trial 12	6.15	5.47	7.54	7.02
Trial 13	6.05	5.5	7.3	6.98
Trial 14	6.17	5.59	7.61	6.76
Trial 15	6.11	5.74	7.52	7.04
Trial 16	6.25	5.46	7.56	7.02
Trial 17	6.25	5.45	7.36	7.01
Trial 18	6.32	5.62	7.53	6.79
Trial 19	6.03	5.58	7.64	6.89
Trial 20	6.23	5.53	7.72	6.95
Trial 21	6.15	5.52	7.56	6.96
Trial 22	6.25	5.61	7.53	7.09
Trial 23	6.12	5.56	7.72	6.79
Trial 24	6.39	5.62	7.71	7
Trial 25	6.22	5.5	7.63	6.86
Trial 26	6.41	5.46	7.39	7.04
Trial 27	6.29	5.6	7.33	7.01
Trial 28	6.03	5.52	7.3	6.83
Trial 29	6.26	5.55	7.42	6.81
Trial 30	6.14	5.53	7.73	6.95
Trial 31	6.28	5.69	7.5	6.93
Trial 32	6.08	5.51	7.35	7.08
Trial 33	6.2	5.56	7.47	6.85
Trial 34	6.1	5.52	7.61	6.78
Trial 35	6.28	5.61	7.55	6.89
Trial 36	6.27	5.47	7.42	6.97
Trial 37	6.14	5.53	7.71	6.91
Trial 38	6.23	5.59	7.63	6.77
Trial 39	6.01	5.58	7.52	6.93
Trial 40	6.19	5.5	7.73	7.02
Trial 41	6.33	5.46	7.31	6.87
Trial 42	6.34	5.71	7.64	7.02
Trial 43	6	5.58	7.59	6.89
Trial 44	6.33	5.46	7.33	7.03
Trial 45	6.25	5.54	7.42	6.9
Trial 46	6.11	5.69	7.53	6.8
Trial 47	6.36	5.69	7.47	7
Trial 48	6.15	5.64	7.74	6.94
Trial 49	6.07	5.63	7.37	6.94
Trial 50	6.28	5.52	7.55	6.79
Trial 51	6.06	5.55	7.64	6.86
Trial 52	6.1	5.74	7.47	7.05
Trial 53	6.21	5.48	7.6	6.8
Trial 54	6.4	5.56	7.43	7.09
Trial 55	6.24	5.72	7.71	6.76
Trial 56	6.26	5.52	7.61	7
Trial 57	6.13	5.48	7.49	6.96
Trial 58	6.23	5.51	7.32	7
Trial 59	6.21	5.64	7.56	6.76
Trial 60	6.28	5.75	7.6	6.77
Trial 61	6.24	5.55	7.49	6.9
Trial 62	6.04	5.73	7.65	6.83
Trial 63	6.27	5.66	7.5	6.99
Trial 64	6.03	5.58	7.59	7.04
Trial 65	6.26	5.5	7.3	6.93
Trial 66	6.18	5.68	7.34	6.85
Trial 67	6.26	5.55	7.44	7.03
Trial 68	6.16	5.57	7.68	7.03
Trial 69	6.39	5.71	7.52	6.98
Trial 70	6.09	5.69	7.32	6.75
Trial 71	6.17	5.72	7.55	6.89
Trial 72	6.09	5.61	7.72	6.85
Trial 73	6.19	5.61	7.58	6.84
Trial 74	6.27	5.63	7.58	6.83
Trial 75	6.41	5.72	7.46	6.89
Trial 76	6.28	5.64	7.74	6.95
Trial 77	6.2	5.66	7.67	7.09
Trial 78	6.08	5.61	7.32	6.82
Trial 79	6.2	5.51	7.36	6.87
Trial 80	6.27	5.75	7.75	7.07
Trial 81	6.16	5.61	7.47	6.79
Trial 82	6.34	5.64	7.67	7.03
Trial 83	6.32	5.73	7.75	6.99
Trial 84	6.03	5.65	7.61	6.76
Trial 85	6.3	5.55	7.35	6.77
Trial 86	6.06	5.59	7.44	7.08
Trial 87	6.33	5.7	7.32	6.81
Trial 88	6.15	5.53	7.32	6.78
Trial 89	6.16	5.71	7.44	6.82
Trial 90	6.14	5.49	7.74	6.83
Trial 91	6.18	5.63	7.34	6.92
Trial 92	6.04	5.62	7.45	6.89
Trial 93	6.1	5.45	7.57	6.83
Trial 94	6.07	5.58	7.47	6.95
Trial 95	6.27	5.52	7.4	6.83
Trial 96	6.26	5.63	7.57	6.81
Trial 97	6.2	5.67	7.33	6.85
Trial 98	6.09	5.63	7.65	6.99
Trial 99	6.15	5.59	7.56	7.1
Trial 100	6.38	5.64	7.47	7.03
Trial 101	6.28	5.63	7.4	6.81
Trial 102	6.26	5.63	7.52	6.97
Trial 103	6.23	5.59	7.31	6.89
Trial 104	6.38	5.66	7.65	6.93
Trial 105	6.07	5.63	7.6	6.86
Trial 106	6.37	5.56	7.63	6.95
Trial 107	6.24	5.66	7.63	6.93
Trial 108	6.04	5.68	7.61	6.88
Trial 109	6.39	5.5	7.49	7.1
Trial 110	6.29	5.73	7.31	7.02
Trial 111	6.2	5.51	7.35	6.79
Trial 112	6.1	5.72	7.39	6.98
Trial 113	6.36	5.49	7.7	6.89
Trial 114	6.27	5.61	7.54	6.94
Trial 115	6.19	5.55	7.4	6.89
Trial 116	6.38	5.56	7.34	6.76
Trial 117	6.35	5.47	7.45	7.08
Trial 118	6.05	5.68	7.44	6.93
Trial 119	6.14	5.51	7.35	7.04
Trial 120	6.08	5.62	7.57	7
Mean	6.20275	5.59275	7.516916667	6.919916667
Standard Deviation	0.109013626	0.083081033	0.135942374	0.100146916

- Total Spent: $13 (under $20)

- Total Weight: 281.6 g (under 435.5 g)

Table 1 shows the data of the deceleration of 32 kg on the surface of the entire foot.

*The lower the value, the less force it took over that time period, so a lower value is better

ANOVA Statistical Test Results

- Walking P-value: 7.43E-126
- Running P-value: 9.70E-105

Both are below .05, therefore I reject my null hypothesis

Data are significant

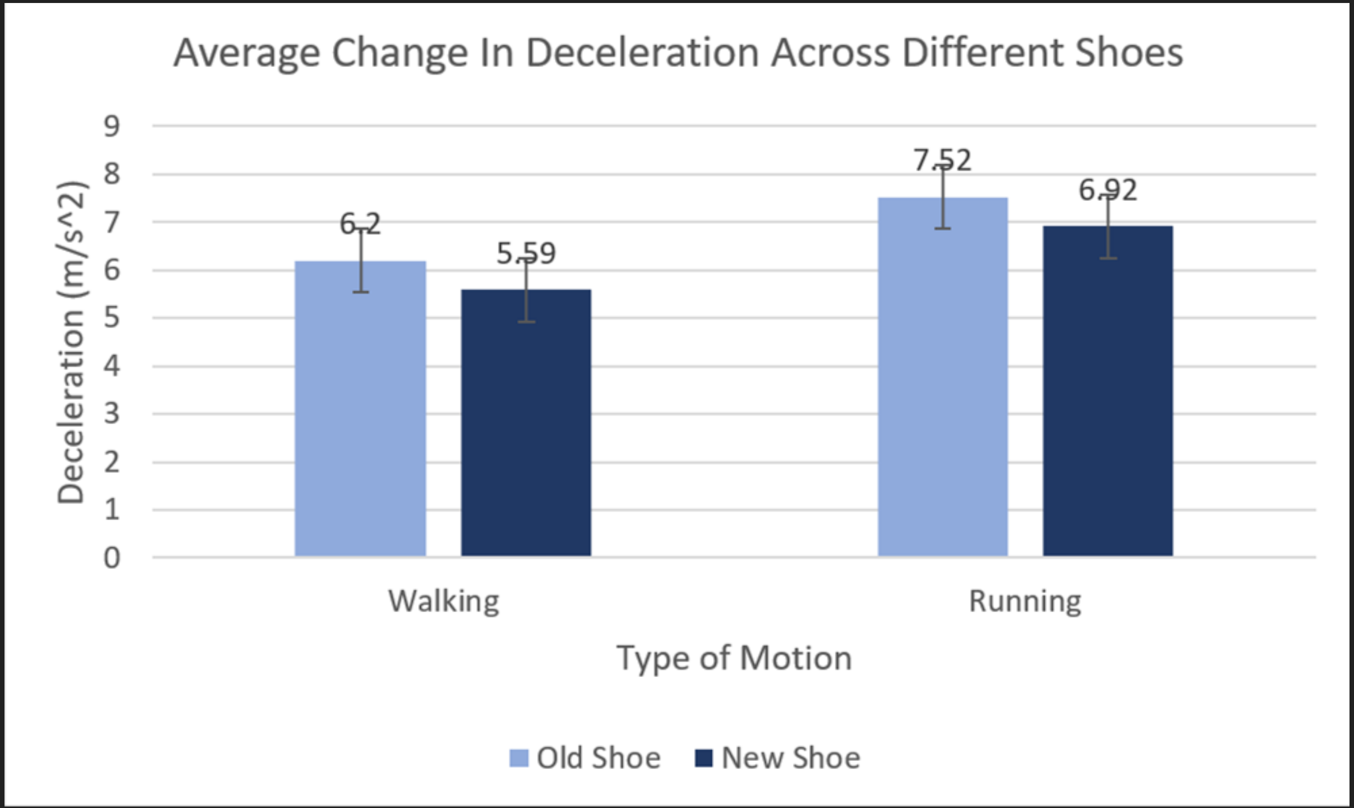


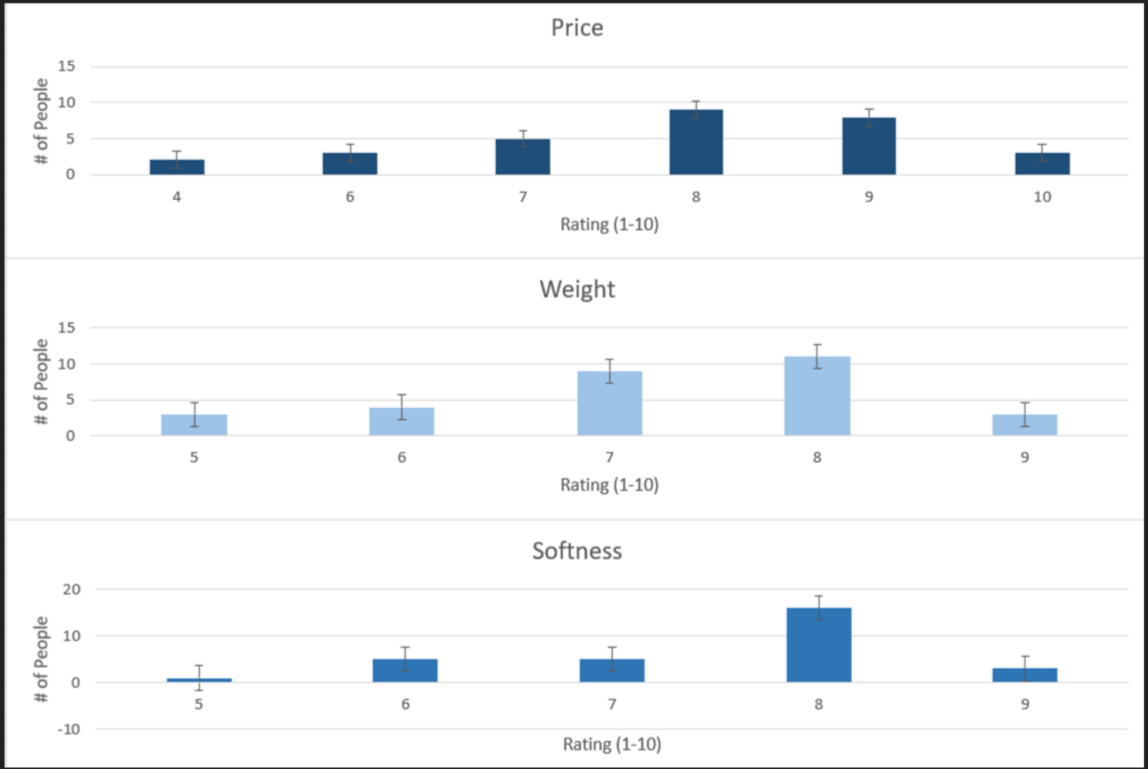
Figure 1: Averages Change in Deceleration Across the 2 Different Shoes Tested

Human Testing Results

30 participants age 60+ were asked to **walk 5 meters**

They were then asked to **rate (1-10)** on 3 criteria using their experience and information provided

1. How **soft** are these compared to your current shoes?
2. How **light** are these compared to your current shoes?
3. How **cheap** are these compared to your current shoes?



Discussion

The new, Halbach-based shoe surpassed the previously developed shoe in the conditions tested. The average change in deceleration for the old shoe was 6.15 m/s^2 while walking and 7.40 m/s^2 while running. The average change in deceleration for the new shoe was 5.54 m/s^2 while walking and 6.92 m/s^2 while running. The ANOVA Test also provided small P-values, meaning the data were significant. These data show that this project was a complete success, as it is stayed under the $20 budget, was far softer than the old shoe (as shown by the deceleration testing), and weighed in at 281.6 g, which is below the constraint. It is more practical over the old shoe because, unlike the old shoe, it has a thin and light sole which gives a barefoot feel, along with a new and distinctive design. In addition to that, it is cheaper due to the lack of foam needed, which utilized a large amount of money. Lastly, it is surprisingly easy and simple to understand, despite the complex scientific concepts behind it. The intent of this project was to redesign the shoe and find a solution for those people how have foot problems, and hopefully this project will provide new hope for those living in pain with a new, highly improved, and distinctive shoe that'll change the way we walk.

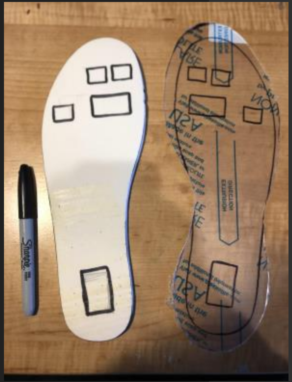
Future Ideas

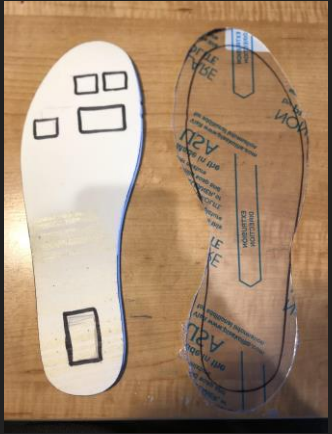
And Improvements on Possible Errors

- Develop In-Shoe Hardware for extra Gait data
  - By collecting data by using piezoelectric pads and a bluetooth-based Arduino to transmit data. This dataset can be used to develop a Machine Learning based app for finding the right shoes and alazylzing gait to develop the best shoe possible.
- Apply this same technology to other areas that require greater cushioning
  - Football helmets could be a great example of an area requiring redesigning due to the amount of head injuries that occur from the lack of sufficient cushioning







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Prototype Z Construction Procedures

Shoe Preparation

1. Cut a shoe plate from a rubber sheet and a polycarbonate sheet of the same size
2. Mark the locations of the magnets on the insole with a Sharpie
3. Place the insole and polycarbonate sheet together and trace the edges and the magnet locations

Magnetic Fixture

1. Place a piece of steel under the insole and place the magnets all facing the same direction using the steel plate to hold them down
2. Apply epoxy and allow time to cure
3. Repeat steps 4-5 for the polycarbonate shoe plate

Final Assembly

1. Place the piece of steel in between the two layers and align them
2. Apply epoxy to only the edges to create a complete bubble and encapsulate that area of magnets
3. Use binder clips to clamp down on the areas of epoxy until cured
4. Move the steel plate accordingly to keep control of magnetic levitation while applying epoxy to the edges
5. Apply epoxy to the unused side of the polycarbonate

Applications & Benefits of the Redesigned Shoe

Current Applications of Magnetic Levitation

- Trains in China and Japan

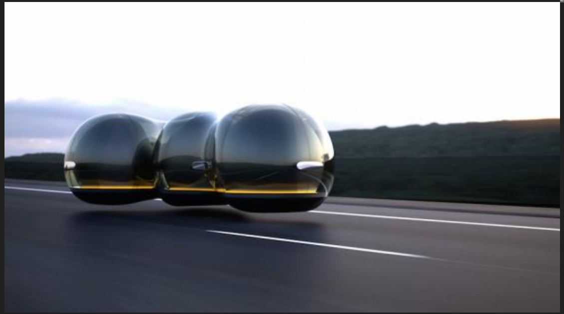
Possible Applications

- Future Cars
- New Magnetic Bearings
- Rapid Travel Shuttles

Benefits of the New Shoe

- A **more effective** form of cushioning
- It’s a **foam** alternative
- **Simpler** technology
- It has **more opportunity** (it’s a new field)
  - Foam has roughly reached its peak in terms of capabilities
- Halbach Arrays give **more power** with the **same size, weight, and cost**

http://www.telegraph.co.uk/technology/0/hyperloop-will-future-transport/



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