Toward Better Posture: A Wearable Back Posture Alerting Device

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Abstract

Back pain is the leading cause of disability worldwide, preventing many people from engaging in work or other everyday activities. Good posture entails training your body to develop a habit that exerts the least amount of pressure on supporting ligaments and muscles; however, posture is not consciously maintained. Instead, muscle groups automatically support and enable flexing of the spine, meaning efforts to consciously improve posture will ultimately fail. Over time, muscles develop habits that can put extra strain on the back and make correcting posture difficult. The greatest contributor to postural problems is poor everyday postural habits, common in a work environment that requires long hours of sitting or standing. Harmful consequences of poor posture include misalignment of the spine, back pain, sore muscles, improper lung function, blood vessel constrictions, improper gait, and proneness to injury. Reversing bad posture should be tackled as soon as the problem is identified, and having an easily accessible posture monitoring device would be useful in preventing long-term detrimental effects of bad posture. In this project, I developed and tested a wearable garment that monitors, evaluates, and communicates real-time sensory feedback on back posture.

Background

Posture is the way someone holds their body while sitting, standing, or performing tasks. Good posture is important for long-term health. As people get older, bad habits such as slouching and inactivity ultimately lead to poor posture and back pain. Posture correction methods most often include exercises to strengthen specific muscles or paying more attention to the alignment of the body (*Back Pain Facts and Statistics, n.d.*).

Depending on the focus area of posture correction, there are different types of posture correctors currently available on the market (*Guide to Good Posture*, 2018). Back posture correctors can be used to correct slouching or other forms of posture by supporting your body in the proper position. The main types of posture correctors are cross-back elastic back braces, longline back braces, electronic posture reminders, and molded upper back braces (During et al., 1985). My project is an electronic posture reminder, which corrects posture by alerting the user whenever they slouch. Vibrations remind people to straighten their back; instead of forcing users into a “correct” position, electronic posture reminders help users train the right muscles to strengthen the back and learn to be more aware of their posture.

Definitions and Current Literature Review

Poor posture has been associated with negative health outcomes and the purpose of this project was to develop a wearable electronic garment to evaluate and improve seated back posture. Current wearable devices and accompanying smartphone applications can provide feedback about shifting posture as well as suggestions that support positive posture awareness. Because people cannot continuously be aware of their posture, biofeedback devices can be utilized to increase someone's awareness of their posture throughout the day, allowing them to improve their posture. According to studies with the 'UpRight' posture feedback device on 59 male and female students aged 19-33 years, using portable biofeedback devices allows participants to become aware of their posture during daily activities, which may help develop skills about posture awareness. More affordable wearable devices can allow the public to receive quality feedback training devices that can improve daily posture (Harvey et al., 2020). Palsson et al. concluded that there is no good quality evidence to support the recommendation of posture-correcting shirts aimed at managing or reducing pain and postural comfort. Wearable posture-correcting garments must be tested for efficacy to assess whether there is a meaningful benefit in the approach (Palson et al., 2019). Yoong et al reviewed many commercially available postural devices such as Upright Go, Lumo lift, Alex, Sense-U, and Prana, and determined that wearable devices capable of measuring and analyzing spinal posture could be promising in the clinical setting for preventing, monitoring, and treating spinal conditions.

Fig. 1. The Upright GO 2 Posture Trainer.

Fig. 2. Alex Posture Trainer and Coach.

However, the challenges in the widespread adoption of these devices include affordability, practicality, and interest. The lack of standardized objective measurements remains an obstacle to continuous monitoring because there is no definite delineation between good and bad posture. Wearable technology could address the inability of lab-based approaches to monitor daily posture. The use of commercial wearables for healthcare in today's world of advancing technologies may also lead to confusion between healthcare professionals and patients, who may utilize different devices to diagnose problems. Wearable technologies are still in their infancy and it remains to be seen how these devices can best serve healthcare (Yoon et al., 2019). More research into the accuracy and long-term outcomes of postural devices is required for a better understanding of their clinical applicability. Furthermore, to improve the magnitude and consistency of results, improvements regarding practicality are required before commercialization and mass uptake can be successful (Simpson et al., 2019). According to a study by Barczyck-Pawelec and Sipko, no self-correction was found in the lumbar spine region, indicating that promoting active self-correction of lumbar lordosis will likely require facilitation and feedback (Barczyck-Pawelec and Sipko, 2016). The majority of current literature agrees that poor posture leads to negative complications, and it can be concluded that an accurate posture monitoring feedback device can improve long-term and daily health, although factors such as cost, true benefit, pain, and comfort must be evaluated.

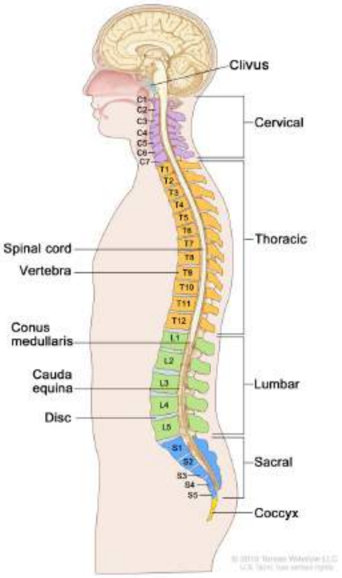


Fig. 3. Side View illustration of 5 portions of the spine (Board et al., 2019).

Methods

Firstly, materials were brainstormed and collected. Various mechanical and electrical design sketches were made and finalized, after which preliminary testing occurred with simple programs and alligator clips. Next, the device was securely fabricated with the materials and further improved with programming in the Arduino IDE. The device was tested on three participants during 30-minute trials. Data from trials were analyzed and visualized to conclude results.

Materials

The components included in the fabrication of this device were:

- FIORA Wearable Electronic Platform
- Lithium-Ion Polymer Battery
- Micro-Lipo USB Charger
- Vibrating Mini Motor Disc
- Haptic Motor Controller
- Stainless Steel Medium Conductive Thread

- Long Flex Sensors (3)
- 10K Ohm Through-Hole Resistors
- Ponte Roma Fabric
- Velcro White Tape
- Soldering Iron Kit
- Alligator Clips
- Digital Multimeter

Fig. 4. Image of main components in device fabrication.

Materials Justification

Because this project was conducted in a home setting, I prioritized affordable and versatile materials that would be easy to design, prototype, and test. The FLORA electronic platform is a wearable electronic platform manufactured by Adafruit. The round, sewable, Arduino-compatible microcontroller uses 3.3V and is powered by a rechargeable lithium-ion battery, which has a cycle life of more than 300 charge cycles. I chose Ponte Roma fabric due to its two-way stretch to allow for user comfort, its medium weight, and its stable, wrinkle-resistant qualities. The long flex sensor was chosen to monitor changes in spine curvature; its longer length allowed for more coverage and its ability to measure change based on how much it was flexed was ideal for this project. Three flex sensors located at two sides and center were used to provide posture monitors in three different directions: front, left, and right. The vibrating mini-motor disc was chosen for electronic feedback. Vibrating buzzes notify the user of changes in posture and times when posture must be corrected.

Design and Sketches

The design of the wearable device can be broken down into two systems: a mechanical system and an electrical system. I cycled through brainstorming and various iterations before deciding on the final design. As I chose between a wearable fabric design and an adhesive of a tattoo-like electronic device, I ultimately chose a fabric substrate due to the more readily available compatible components, its easier fabrication process, and most importantly, its durability and reusability. Two main fabric substrate designs were considered: an adjustable belt design, and a garment such as a shirt or a vest. I chose the belt design because of its adjustability and ease of wearing. Adjustability is crucial to this wearable device because garments must be well-fitted in order to accurately monitor posture. Ease of use is important in making it practical for continuous wear as well as improving its durability by limiting wear down caused by friction and constant motion of the parts. All components were sewn on, soldered, or attached through fitted pockets.

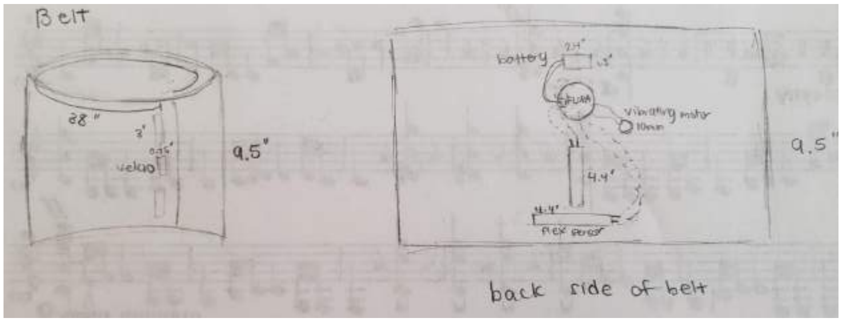


Fig. 5. Initial Mechanical System Diagram.

This mechanical system diagram features an adjustable velcro belt design with two flex sensors and a vibrating mini-motor disc. The aim of the second horizontal flex sensor was to offer a way to measure the sideways curvature of the spine alongside regular slouching. However, I soon realized that a horizontally placed flex sensor would not return the results for sideways curvature that I hoped for due to the way in which the sensor bends.

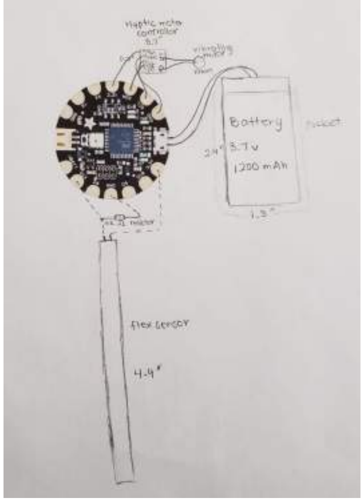


Fig. 6. Electrical System Diagram.

The first electrical system diagram was a preliminary rough diagram as I was still figuring out how all the parts would connect and fit together. I only placed one flex sensor and I placed the battery vertically next to FLORA so that it could easily sit securely in a pocket. The haptic motor controller is connected to the vibrating motor and the long flex sensor is connected by conductive thread.

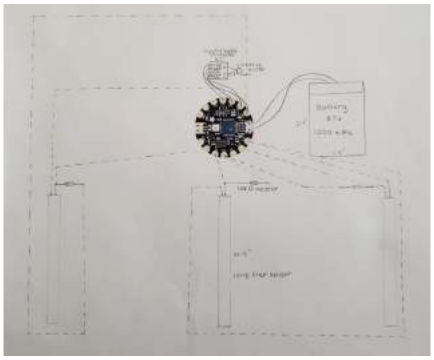


Fig. 7. Electrical System Diagram 2.

In order to accomplish my goal of being able to monitor slouching and sideways bending, I decided the optimal design would include three flex sensors, with the two side flex sensors positioned at the side of the body where the torso bends. This diagram includes connections of all flex sensors using conductive thread. Since conductive thread cannot cross paths, some thorough brainstorming was needed to settle on this electrical system diagram. I decided that the haptic motor controller would be connected by small flexible wires because there were no paths of connection available that wouldn't cross other paths.

Final Designs

The final mechanical and electrical system diagrams include an adjustable velcro belt on which FLORA, 3 long flex sensors, a battery, a haptic motor controller, and a vibrating motor are attached.

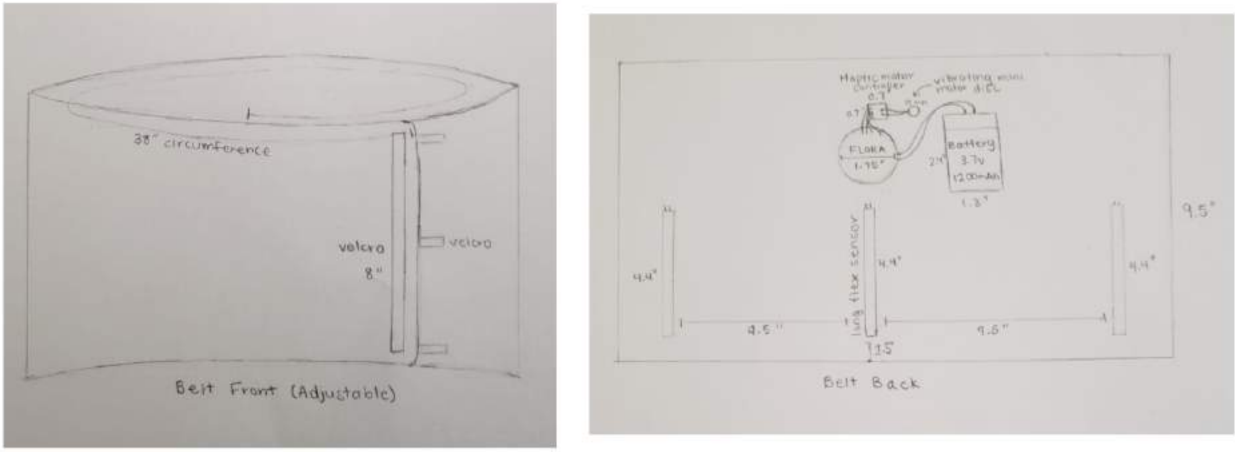


Fig. 8. Mechanical System Diagram of Front and Back Components.

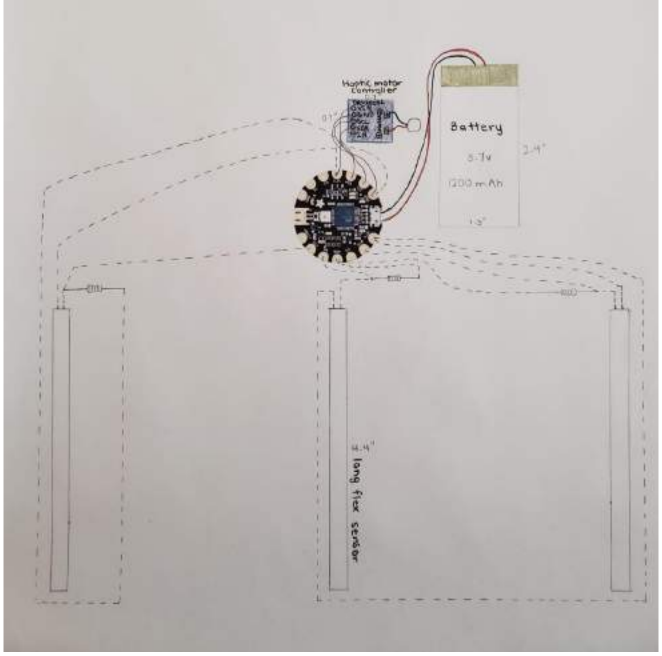


Fig. 9. Electrical System Diagram.

Fabrication

The three main parts of fabricating the devices were: sewing the adjustable belt piece, prototyping and attaching the electrical parts, and programming and testing the device.

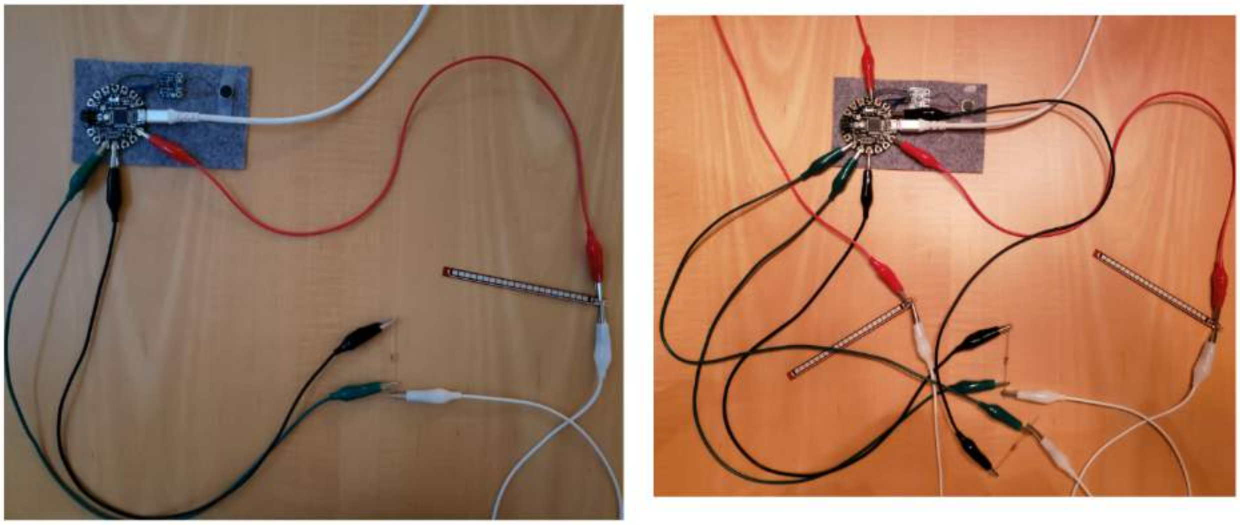


Fig. 10. Testing circuitry and code with alligator clips.

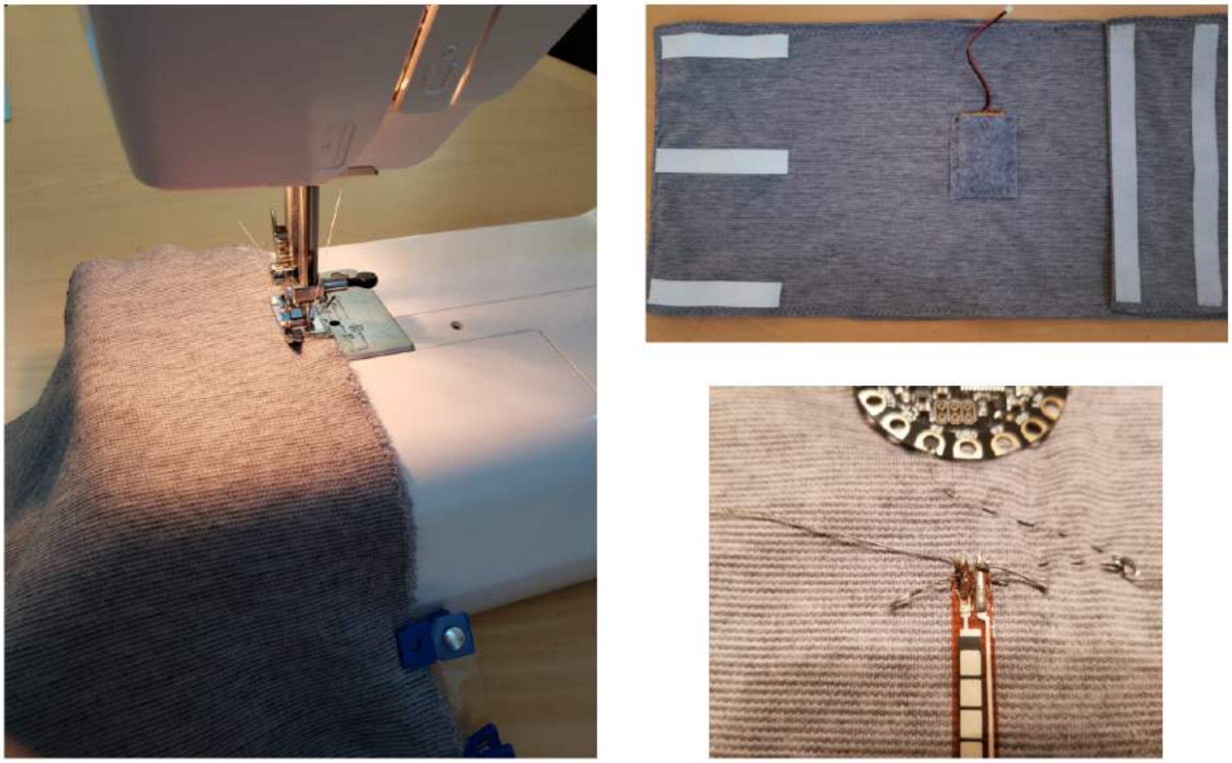


Fig. 11. Sewing and attaching components onto fabric.

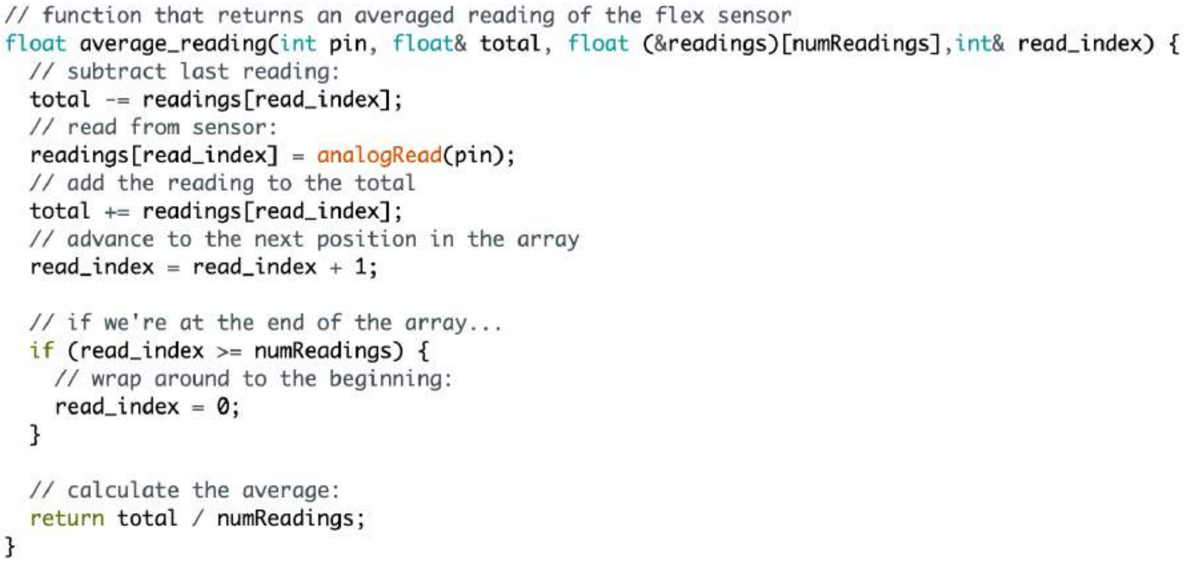
Fig. 12. Using conductive thread to connect electrical paths.

The fabrication process of the belt took much longer than originally anticipated, mostly due to the delicacy of the components. The mini vibrating motor connection broke several times because the wires were so delicate, so I reinforced the final product with electrical tape. Ensuring good connections from the conductive thread to the flex sensors was also quite challenging because the nature of the thread made it so that the solder would never melt directly onto the thread.

Programming

The main steps to program the device were:

1) Initialize all digital pins, readings, and bend thresholds
2) Read the three flex sensors and average the readings to reduce noise
3) Compare flex sensor readings to bend threshold, alert user if bend has surpassed threshold

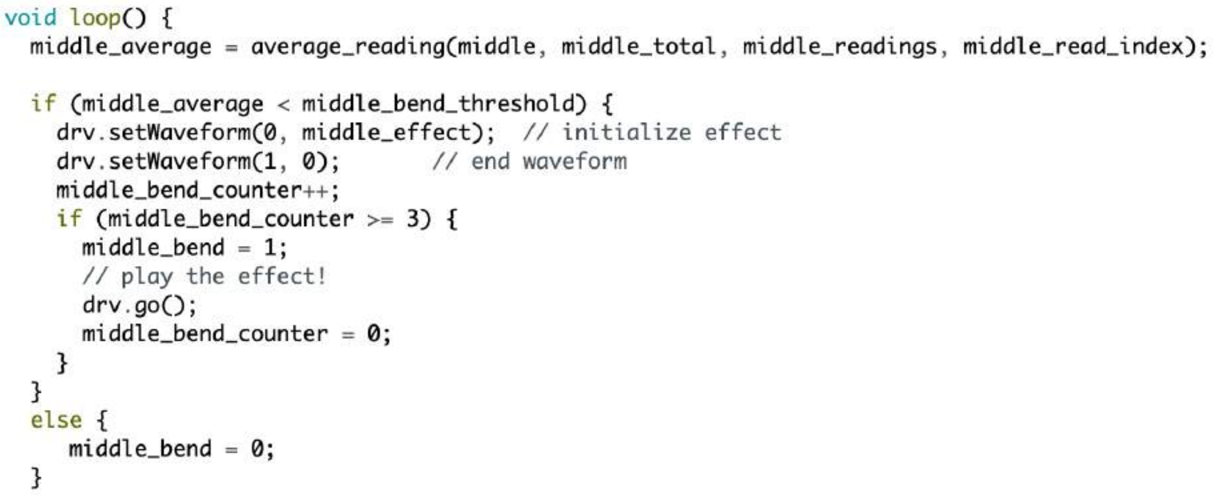


```
// function that returns an averaged reading of the flex sensor
float average_reading(int pin, float& total, float (&readings)[numReadings],int& read_index) {
  // subtract last reading:
  total -= readings[read_index];
  // read from sensor:
  readings[read_index] = analogRead(pin);
  // add the reading to the total
  total += readings[read_index];
  // advance to the next position in the array
  read_index = read_index + 1;

  // if we're at the end of the array...
  if (read_index >= numReadings) {
    // wrap around to the beginning:
    read_index = 0;
  }

  // calculate the average:
  return total / numReadings;
}
```

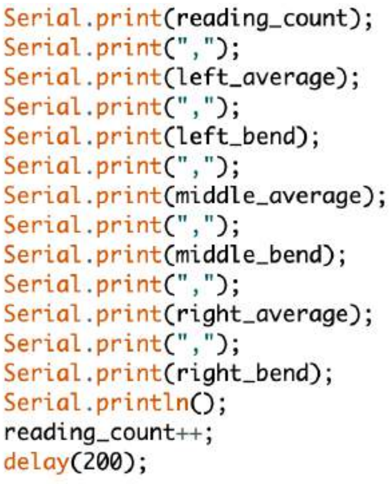
Fig. 13. Averaging Function in Arduino. This function is an important part in getting readings from the flex sensor. It is used to average out readings from all three flex sensors and return an averaged reading which is checked against a bend threshold.



```
void loop() {
  middle_average = average_reading(middle, middle_total, middle_readings, middle_read_index);

  if (middle_average < middle_bend_threshold) {
    drv.setWaveform(0, middle_effect);  // initialize effect
    drv.setWaveform(1, 0);       // end waveform
    middle_bend_counter++;
    if (middle_bend_counter >= 3) {
      middle_bend = 1;
      // play the effect!
      drv.go();
      middle_bend_counter = 0;
    }
  }
  else {
     middle_bend = 0;
  }
```

Fig. 14. Image of Code Sequence to Trigger Haptic Motor. In the loop, I checked each flex sensor's averaged reading with a bend threshold to decide whether to vibrate the mini motor to alert the user.



```
Serial.print(reading_count);
Serial.print(",");
Serial.print(left_average);
Serial.print(",");
Serial.print(left_bend);
Serial.print(",");
Serial.print(middle_average);
Serial.print(",");
Serial.print(middle_bend);
Serial.print(",");
Serial.print(right_average);
Serial.print(",");
Serial.print(right_bend);
Serial.println();
reading_count++;
delay(200);
```

Fig. 15. Print Statements at the End of Arduino Code. These series of print statements will be displayed on the serial monitor. They are organized in a way to be separated by commas and easily decoded to put into a data frame.

```
ser = serial.Serial('/dev/cu.usbmodem14101')
ser.flushInput()

#Data example: 10,524.50,0,433.79,448.29,0

columns = ['timestamp', 'left', 'left bend', 'middle', 'middle bend', 'right', 'right bend']
df = pd.DataFrame (columns=columns)

while True:
    try:
        ser_bytes = ser.readline()
        text = ser_bytes[0:len(ser_bytes)-2].decode("utf-8")
        #Split data into list of string tokens
        tokens = text.split(",")
        #Change tokens into floats
        floats = [float(x) for x in tokens]
        #temporary dataframe
        temp_df = pd.DataFrame([floats], columns=columns)
        df = df.append(temp_df, ignore_index=False)


    except KeyboardInterrupt:
        print("KeyboardInterrupt")
        #Save dataframe as csv file
        df.to_csv('sensor_data.csv', index=False)
```

Fig. 16. Code Snippet From Python Decoding. Python code stores and reads the data from Arduino into a CSV file for testing.

Final Product

Simply connect a charged battery, wear and adjust the fabric piece with the velcro, and go about daily work periods with alerts to remind you to adjust your posture!

Fig 17. Image of Device Being Worn and Electrical Paths.

Participants and Procedure

After writing the code to store and visualize the data, I tested the efficacy of the device, on three volunteer subjects. All data remained anonymous. The trials lasted 30 - 45 minutes long, and the device was connected to a laptop to collect and record data that would be reviewed later. During the trials, each user was seated at a desk, completing a work period (e.g. working with a laptop, writing notes, reading a book)

Results and Data Processing

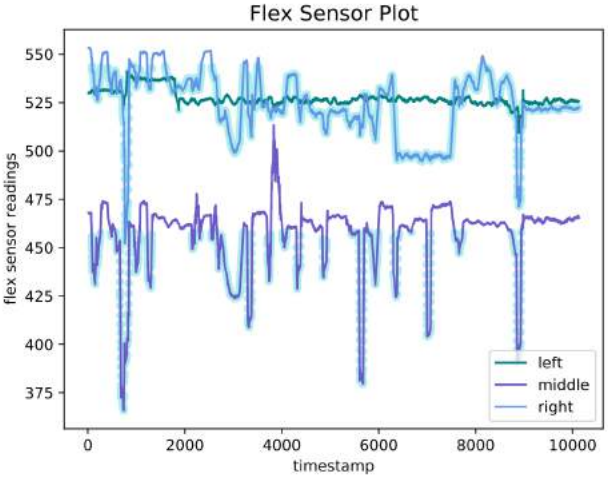


Fig 18. 30 - 45 minute trial for user 1.

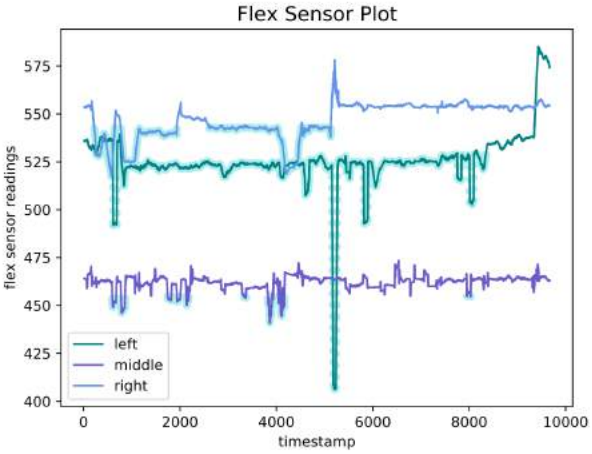


Fig. 19. 30 - 45 min trial for user 2.

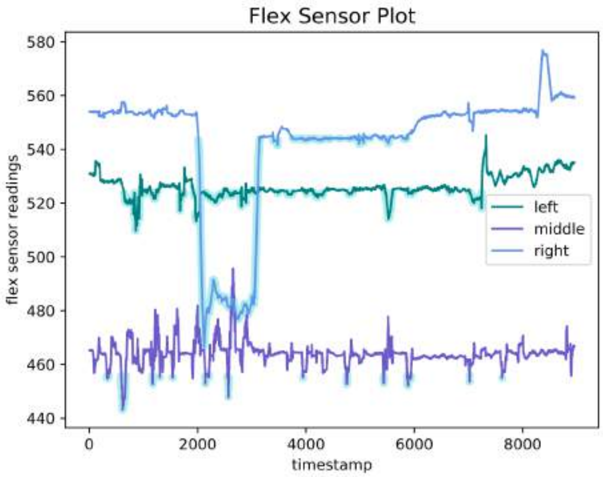


Fig. 20. 30 - 45 min trial for user 3.

Using the plotted data, the results from user trials indicate a trend of users straightening their posture after being notified of a bend; blue dots mark points when the flex sensor bend was under the bend threshold, activating a vibration alert. With CSV data collected from all three users, my results are as follows:

Table 1. Results from Three User Trials.

	User 1	User 2	User 3	Average
% Trial in Bent Position	88.98%	35.74%	82.43%	69.05%
% Bent in First 8 Minutes	96.58%	43.5%	88.25%	76.11%
% Bent in Last 8 Minutes	67.38%	9.67%	41.25	39.43%
Average Response Time to Haptic Feedback (seconds)				
Left Sensor	2.30	3.90	3.98	3.39
Middle Sensor	2.63	4.67	2.68	3.32
Right Sensor	3.47	3.53	3.55	3.51

Note. Average response time more accurately indicates correction time after the haptic motor was triggered. Users generally responded to alerts faster but took some time to fully adjust and correct their posture. Outliers (times over 12 seconds or under 1 second) were ignored.

In all three trials, the percentage spent in the bent position decreased in the last minutes of the trial compared with the first minutes. On average, users took 3.4 seconds to respond to haptic feedback and correct their posture.

Limitations

My results were limited by the accuracy and sensitivity of Adafruit's flex sensors, the sensors used to detect bends, and changes in posture. Lack of sensitivity to change meant that the posture readings may not always have been accurate or would require far larger changes to reveal poor posture. In addition, due to the nature of the flex sensors, after a bend, it takes some time for the flex sensors to straighten out to their starting position, causing the slouch occurrences to appear more frequent and long-lasting. With more sensitive and high-end flex sensors, the results of detecting slouching would be largely improved. The wearable device measures lumbar posture, which supports majority of the upper spine. However, straightening lumbar posture does not necessarily mean the entire spine is straight, as the upper back could still slouch while the lumbar area is upright. The current COVID-19 pandemic situation limited my ability to broaden user testing. In the future, I aim to increase participant trials to gather and analyze more data. Based on feedback from participants, a future improvement to the device could include separate haptic motors located near each flex sensor. With just one vibrating motor, vibration patterns can be hard to distinguish and take time to learn. Placing separate haptic motors by each area of the spine could potentially improve response time to haptic feedback. In addition, I hope to improve the ease of use and lower the cost of the device. Most of the cost of the device came from the flex sensors, which were the most important component of the device. My original hope when thinking of this device was to fabricate something that could easily be attached and removed, such as a silicone adhesive electric device, which would be slightly lower in cost and much easier to attach and remove. However, for simplicity and comfort, I opted to go with a wearable fabric device with easily purchasable parts that could help an inexperienced innovator be creative. Overall, my device showed that a wearable electronic garment can be an effective, low-cost method of monitoring and improving long-term lumbar back posture in daily life situations. The design and final product turned out how I envisioned, and data processing and testing revealed that users respond well to alerts to straighten the back.

Conclusion

With poor back posture being a common cause of long-term consequences, maintaining proper posture is something that everyone struggles with. Posture cannot be conscientiously improved, which often results in worsening postural habits (*Why is it hard to maintain good* *posture*, 2021). My goal was to create a simple, wearable posture monitoring device that could alert users of poor posture to encourage them to maintain better posture during periods of use. The results of my project suggest that wearable posture monitoring devices prove to be effective and viable products targeted at users who wish to improve their posture. With regular use during periods of work, wearable posture alerting devices prove to offer a solution to maintaining proper posture. The overall cost of the materials used in fabricating the device was approximately $65, which is comparable to or below similar items on the market. To come to more definitive conclusions about wearable haptic devices, more research into long-term outcomes and applicability will be needed. An area of future interest would be the adoption of wearable technology into the commercial market, which will require consistent results, improvements aimed to assist users, and evaluations on general pain or comfort. Regardless, my findings point to the need for medical practitioners to consider adopting wearable technology as a simple option to help patients maintain healthy, beneficial habits.

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