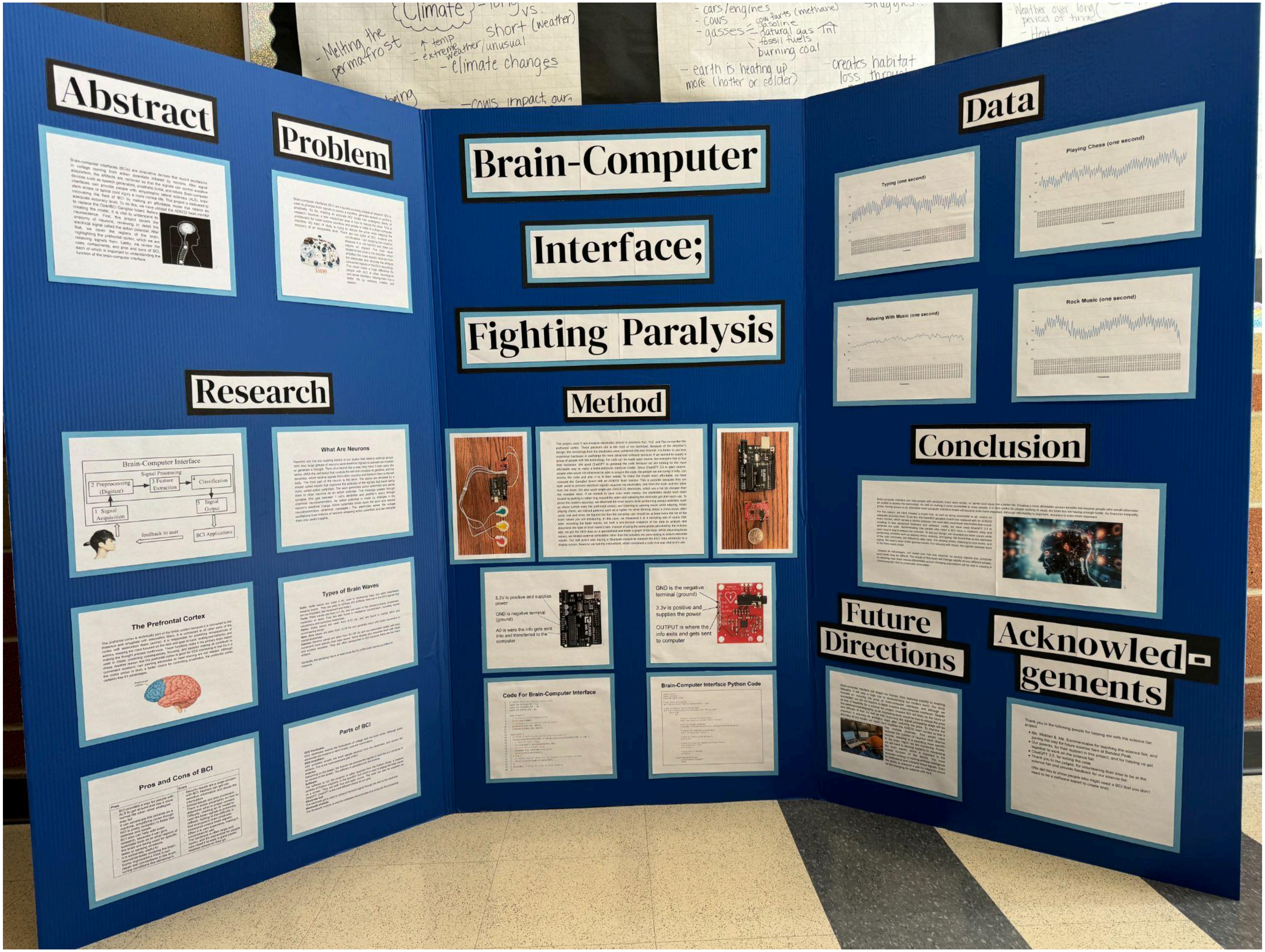
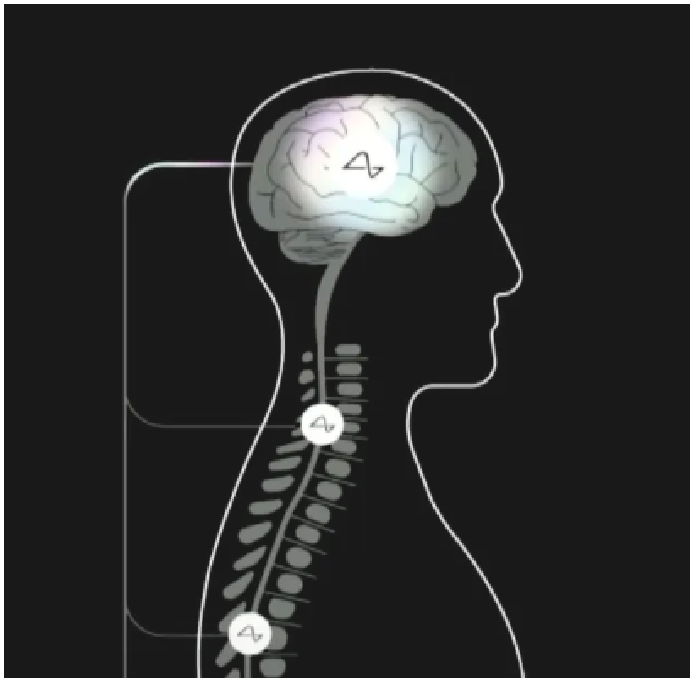
This document contains everything that is on our science fair board. If the picture of the board is too blurry to see, you can scroll down to view it's components.



Abstract

Brain-computer interfaces (BCIs) are innovative devices that record oscillations in voltage coming from action potentials initiated by neurons. After signal acquisition, the artifacts are removed so that the signals can control assistive devices such as speech generators, prosthetic limbs, and robots. Brain-computer interfaces can provide people with amyotrophic lateral sclerosis (ALS), brain stem stroke or spinal cord injury a more normal life. This project is dedicated to innovating the field of BCI by making an affordable model that retains an adequate accuracy level. To do this, we have utilized the AD8232 heart monitor to replace the OpenBCI Ganglion board. Before creating the model, it is vital to understand its neuroscience. First, this project covers the anatomy of neurons, reviewing in detail the electrical signal called the action potential. After that, we cover the regions of the brain, highlighting the prefrontal cortex, which we are receiving signals from. Lastly, we review the uses, components, and pros and cons of BCI, each of which is important to understanding the function of the brain-computer interface.



Problem

Brain-computer interfaces (BCI) are a quickly evolving subject of research. BCI is used to process brain signals to control a machine, generate speech or control a prosthetic. So far, creating an accurate BCI model has undergone plenty of research, however, a less researched area is how to reduce the price. This is problematic for lower-income countries and people in need of a Brain-computer interface. My topic of study is trying to reduce the price while keeping the accuracy at an acceptable level. There are two types of BCI, invasive and non-invasive. I am studying non-invasive because it is not harmful and does not require an implant. The main issue related to the price is the amplifier, which amplifies the weak signals received from the electrodes and removes the artifacts (unwanted signals in the EEG recording). This could make a huge difference for people with ALS or other neurological and spinal disorders, helping them live a better life by restoring mobility and speech.

What Are Neurons

Neurons are the tiny building blocks of our brains that receive external stimuli. With that, large groups of neurons send electrical signals to activate our muscles or generate a thought. Think of a neuron like a tree; they have 3 main parts, the soma, (AKA the cell body) that controls the cell and contains its genetics, and the dendrites, which receive signals from other neurons and transmit them to the cell body. The third part of the neuron is the axon. The axons are encased by a sheath called myelin that improves the potential of the signals that travel along them, called action potentials. The axon generates action potentials and sends them to other neurons as an action potential. This message passes through synapse (the gap between 1 cell's dendrites and another's axon) through chemical neurotransmitters. An action potential is made by changes in the neuron's electrical charge. Action potentials travel down the axon and release neurotransmitters (chemical messages.) The electrodes sense the voltage oscillations from millions of neurons releasing action potentials and can decipher them into useful insights.

Types of Brain Waves

Delta: Delta waves are under 4 Hz, seen in developing baby and adult dreamlessly sleeping brains. They are easy to confuse with artifacts (features in the EEG signals that are not important, like movement and noise.)
Theta: Theta waves are from 4-7 Hz, and are seen in the children's brains, drowsiness, meditation or sleep. They are also found in meditative concentration, including mental calculations and conscious awareness.
Alpha: Alpha waves are seen from 8-12 Hz, and are found in mental effort and remembering things.
Beta: Beta waves are seen from 12-30 Hz and generally occur with motor movement or mental awareness.
Gamma: Gamma waves are seen from 30-100 Hz and are associated mostly with body movement more actively than beta waves. Some studies also associate them with visual and auditory reception. They are often disregarded in BCI because there are too many artifact

Generally, the sampling rate is at least twice the Hz of the brain waves you intend to measure.

Parts of BCI

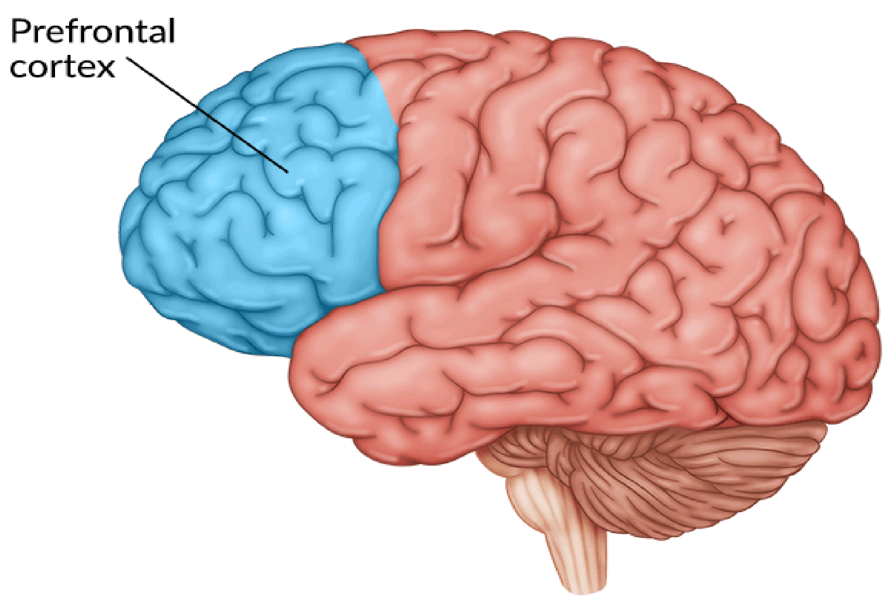
EEG Electrodes:
EEG electrodes record the fluctuations of voltage that the brain emits. Although some electrodes are invasive or semi-invasive, ours are non-invasive.
EEG Amplifiers:
EEE amplifiers amplify the weak signals received from the electrodes and remove the artifacts. This is the most expensive part of BCI.
Arduino:
Depending on the design, the Arduino can process the signals or send them to a computer to be viewed on the screen. The software is uploaded onto the Arduino.
Software:
The software to run the program is either acquired from the Python library, a massive portfolio of Python programs, or the openBCI GUI which is used to display the brain waves on a screen. They are both free and open source. The code can also be acquired via ChatGPT. ChatGPT is the most efficient choice for our goal.
Electrode Gel:
The electrode gel is used to conduct the brain signal through the skin to the electrode.
Bluetooth module:
The Bluetooth module is used to wirelessly transmit data to a computer for processing.

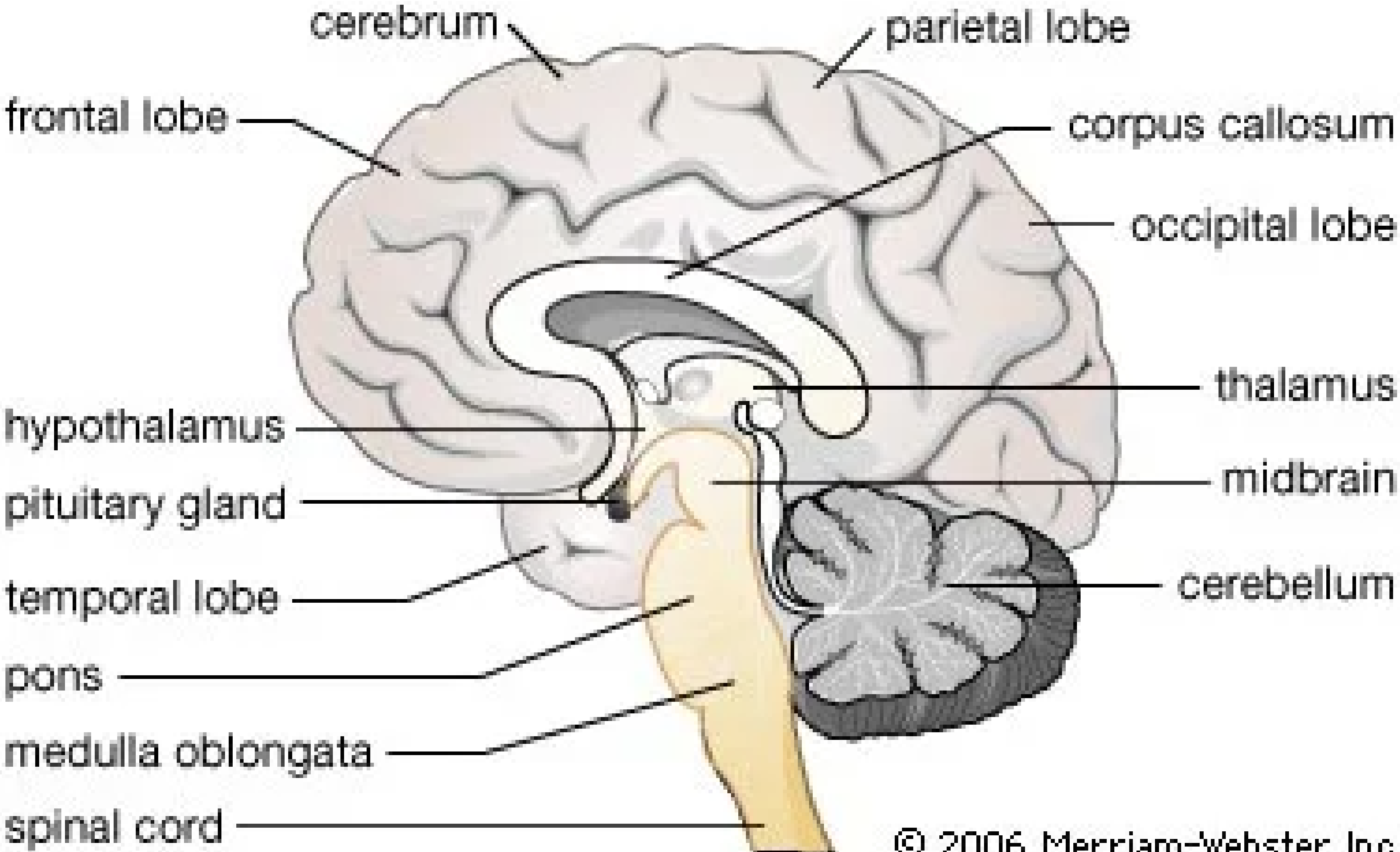
Pros and Cons of BCI

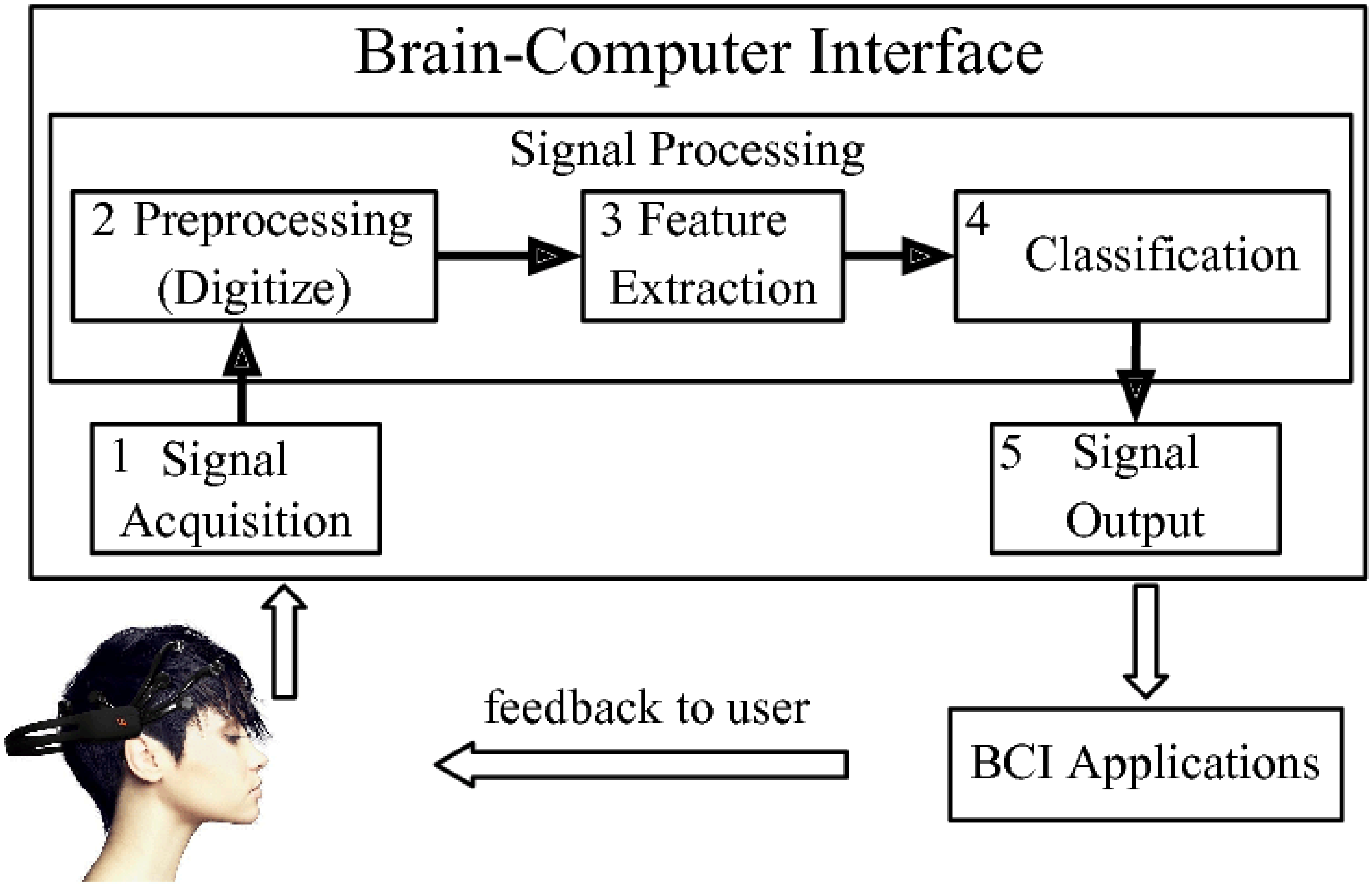
Pros	**Cons**
- BCI provides a way for people with ALS to get around and live a more normal life when other strategies may fail. - It can accelerate the controls on a machine, simplifying (even though BCI is pretty complex) fields like defense and space. - BCI also can help with brain research, because it can give scientists hints as to what regions of the brain are being used for specific tasks or sensing emotions. - It is extremely useful to neuroscientists studying the brain. - Some organizations think it can repair lost connections in the brain, curing conditions like alzheimer's.	- Security issues are a large concern with BCI; hackers can get into sensitive information and abuse the information. - Ethical issues are also prominent. There is some uncertainty on how to determine what is proper consent. - Difficulty; creating an AI model to read the brain signals is extremely difficult. Adding to the difficulty is that everyone’s brain produces somewhat unique brain signals. - Often it is very expensive, making it uncommon to use. - The hardware is often large and clunky, and it’s impractical for people who need it to wear a giant plastic headset wherever they go.

The Prefrontal Cortex

The prefrontal cortex is technically part of the limbic system because it is connected to the thalamus and amygdala with association fibres. It is connected to all other parts of the cortex with association fibers (axons). It is responsible for predicting the consequences of actions, keeping the mind focused on the task and goal at hand, limiting bad behavior, and making the thought process continuous. These functions make it the primary brain region used in chess; predicting consequences, focusing, and decision-making all contribute to chess. Another reason that the prefrontal cortex is good for EEG monitoring is that it's in convenient locations; hair-piercing electrodes or head shaving are not needed. Although the motor cortex is likely a better choice for controlling prosthetics, the prefrontal cortex certainly has its advantages.



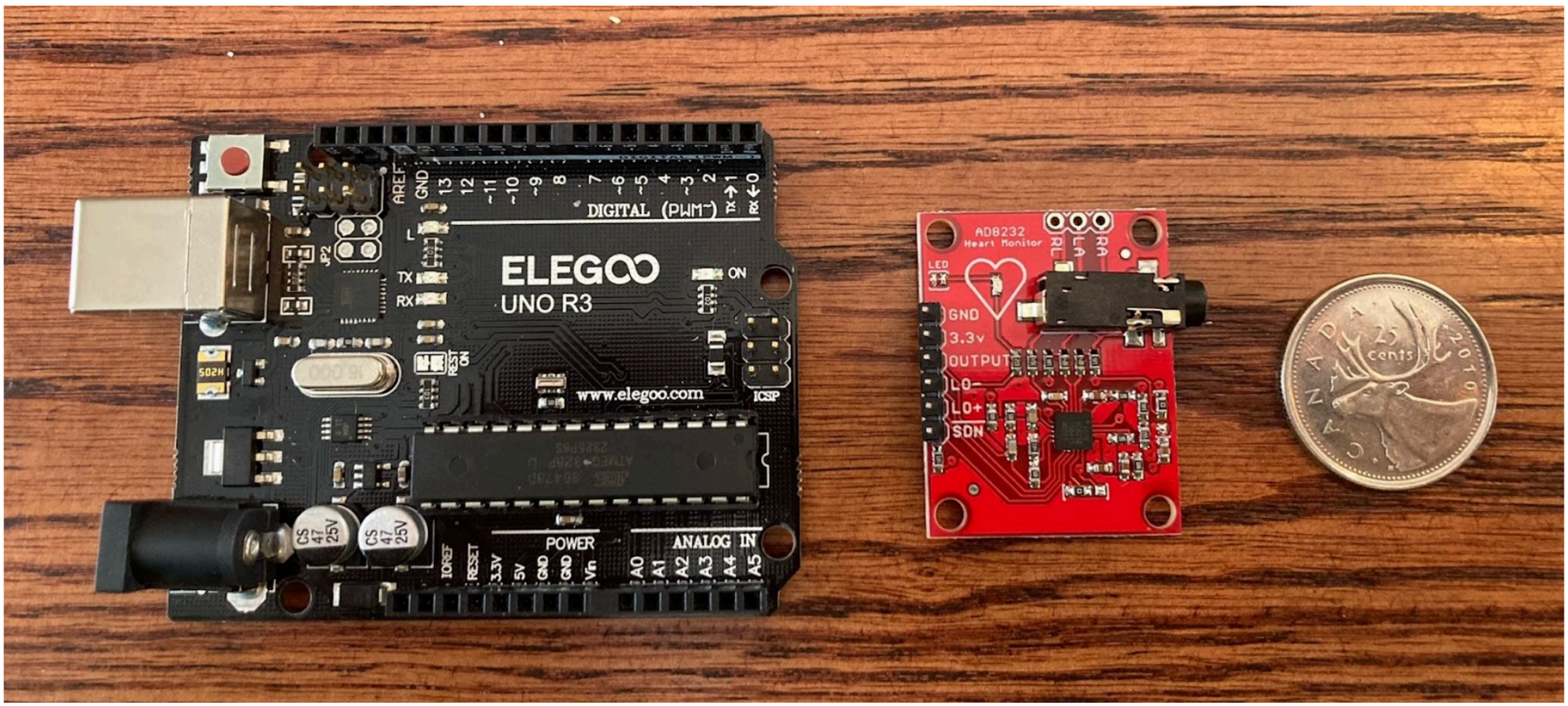

cerebrum
parietal lobe
frontal lobe
corpus callosum
occipital lobe
thalamus
hypothalamus
midbrain
pituitary gland
cerebellum
temporal lobe
pons
medulla oblongata
spinal cord

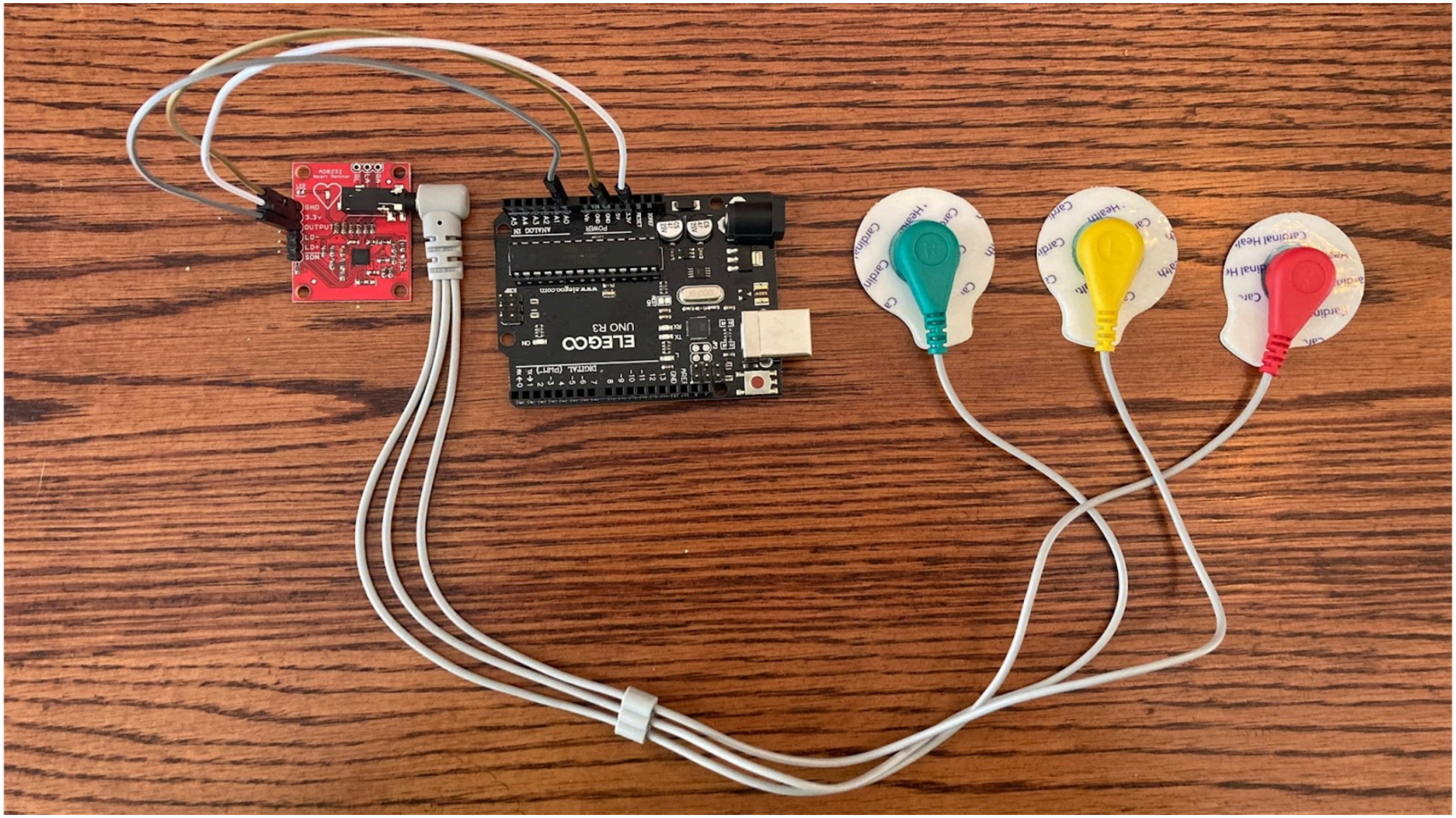

Brain-Computer Interface
Signal Processing
2 Preprocessing (Digitize)
3 Feature Extraction
4 Classification
1 Signal Acquisition
5 Signal Output
feedback to user
BCI Applications

Method

This project used 3 non-invasive electrodes placed in positions Fp1, Fp2, and Fpz to monitor the prefrontal cortex. These positions are at the front of the forehead. Because of the amplifier's design, the recordings from the electrodes were combined into one channel. It is better to use less expensive hardware in exchange for more advanced software because if we wanted to supply a group of people with this technology, the code can be made open source, but everyone has to buy their hardware. We used ChatGPT to generate the code because we are looking for the most affordable way to make a brain-computer interface model. Since ChatGPT 3.5 is open source, people who would not otherwise be able to acquire the code, the people we are trying to help, can access the code and alter it to fit their needs. To make the model more affordable, we have replaced the Ganglion board with an AD8232 heart monitor. This is possible because they are both used to process electrical signals acquired via electrodes; one from the brain and the other from the heart. We also used single-use EMG/ECG electrodes, which are a fair bit cheaper than the reusable ones. If we wanted to save even more money, the electrodes could have been reused by putting a rubber ring around the sides and replacing the electrode gel after each use. To prove the model's accuracy, we observed the brain waves while performing various activities, such as chess (which uses the prefrontal cortex) and listening to calming music while relaxing. While playing chess, we noticed patterns such as a higher Hz while thinking about a chess move. After some trial and error, we figured out that the sampling rate should be at least twice the Hz of the brain waves you are measuring. In this case, we measured it at a sampling rate of nearly

200. After recording the brain waves, we took a one-second snapshot of the data to analyze and determine the type of brain wave it was. Instead of using the serial plotter provided by the Arduino app, we put the EEG data on a spreadsheet and made a graph of the data. While observing brain waves, we limited external stimulation other than the activities we were testing to ensure accurate results. Our last action was to buy a Bluetooth module to transmit the EEG data wirelessly to a display screen, however, we lost the instructions, which contained a code that was vital to its use.

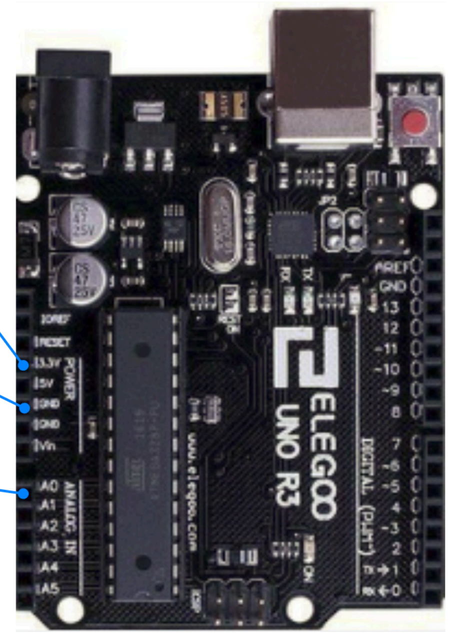




3,3V is positive and supplies power

GND is negative terminal (ground)

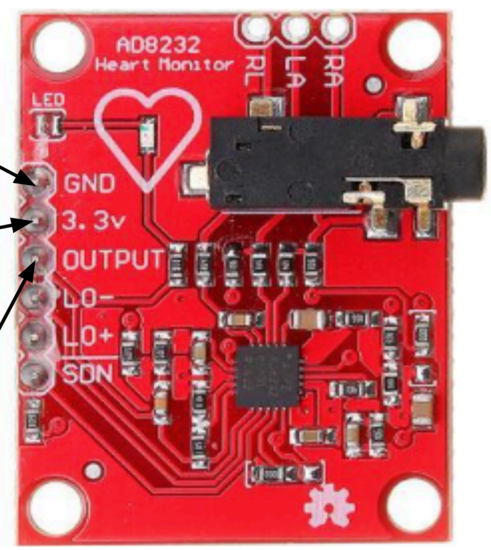
A0 is were the info gets sent into and transferred to the computer



GND is the negative terminal (ground)

3.3v is positive and supplies the power

OUTPUT is where the info exits and gets sent to computer

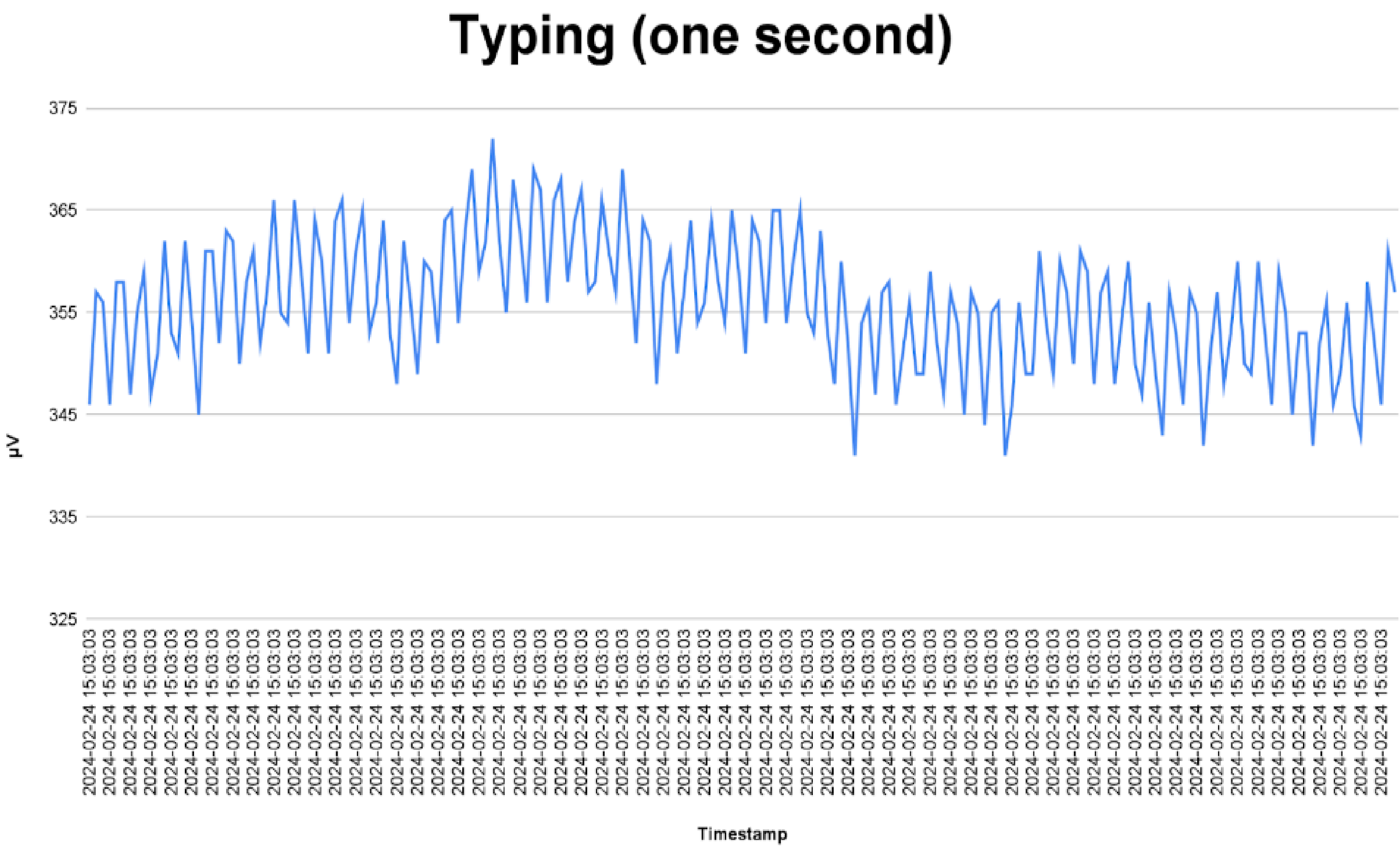


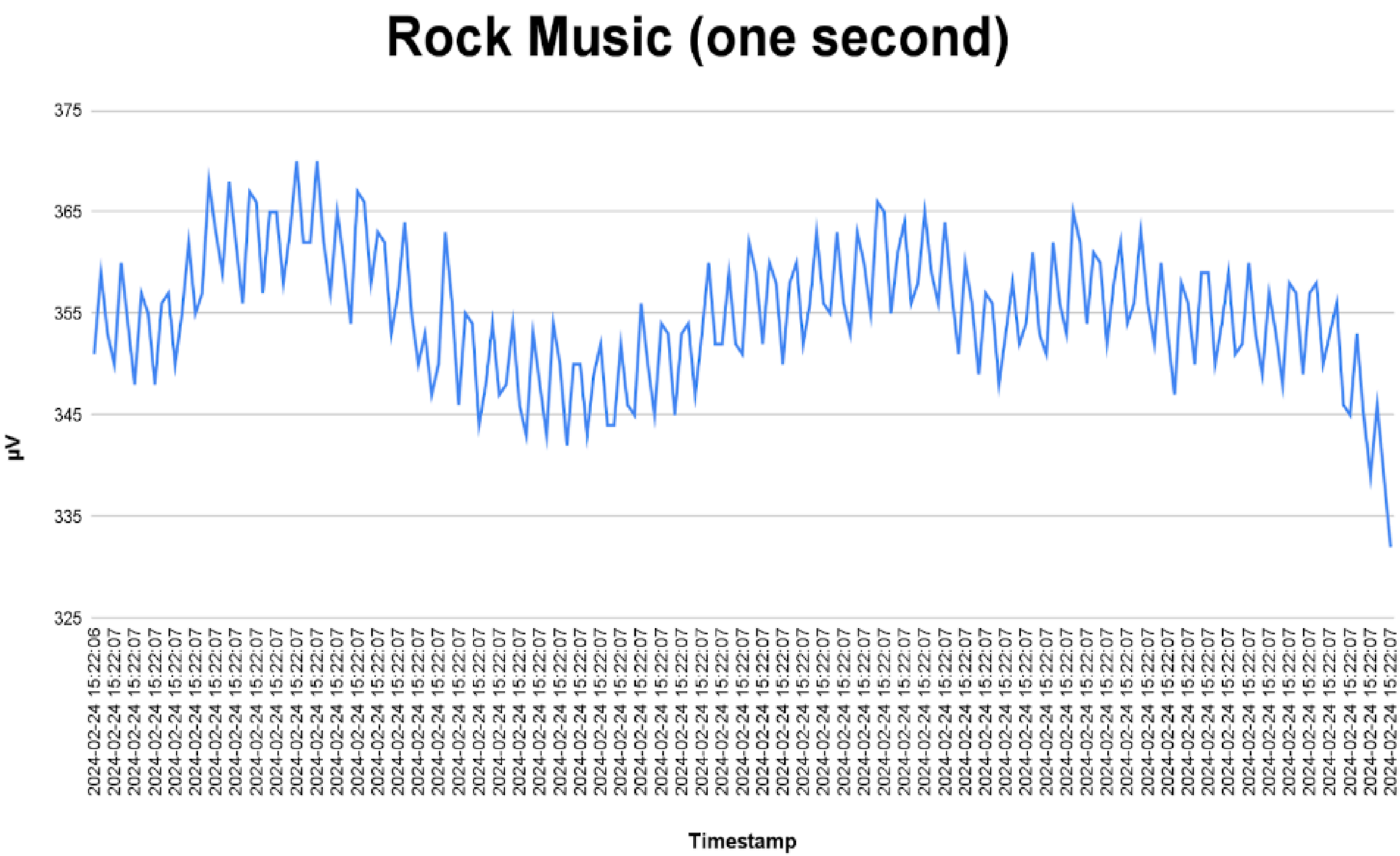
Code For Brain-Computer Interface

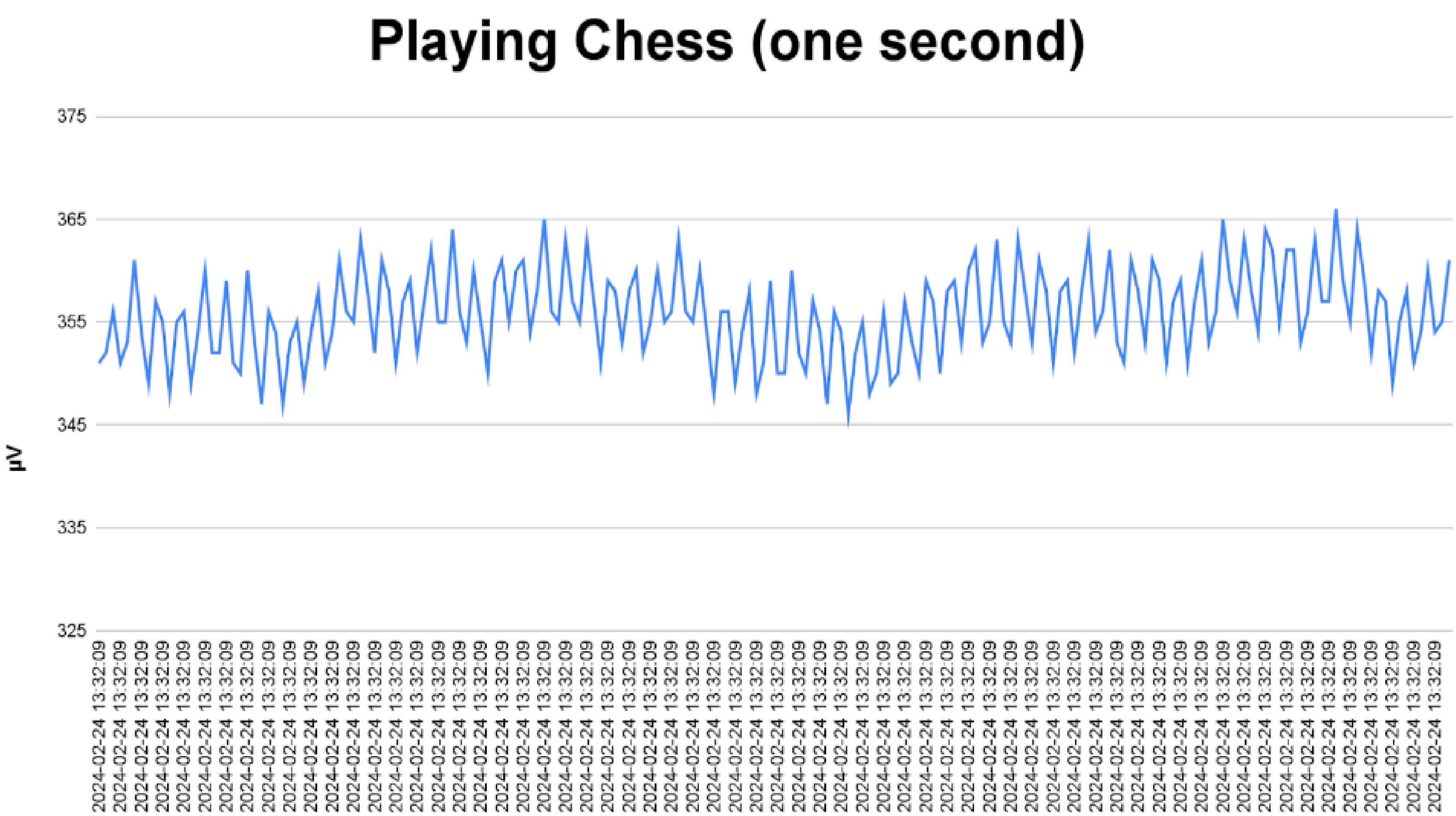
```
// AD8232 Heart Rate Monitor Hookup Guide
const int LO_PLUS_PIN = 11;
const int LO_MINUS_PIN = 10;
const int OUTPUT_PIN = A0;

void setup() {
  // Initialize Serial Communication
  Serial.begin(9600);
  // Configure the LO+ and LO- pins as inputs
  pinMode(LO_PLUS_PIN, INPUT);
  pinMode(LO_MINUS_PIN, INPUT);

void loop() {
  // Check if both LO pins are not detecting lead off
  if(digitalRead(LO_PLUS_PIN) == LOW && digitalRead(LO_MINUS_PIN) == LOW) {
    // Read the heart signal
    int bciSignal = analogRead(OUTPUT_PIN);
    // Print the bciSignal value
    unsigned long timestamp = millis();
    Serial.println(bciSignal);
  } else {
    // Handle lead off detection, for example by printing a message
    Serial.println("Lead off detected");
  }
  delay(50); // Delay for a bit to avoid spamming
}
```

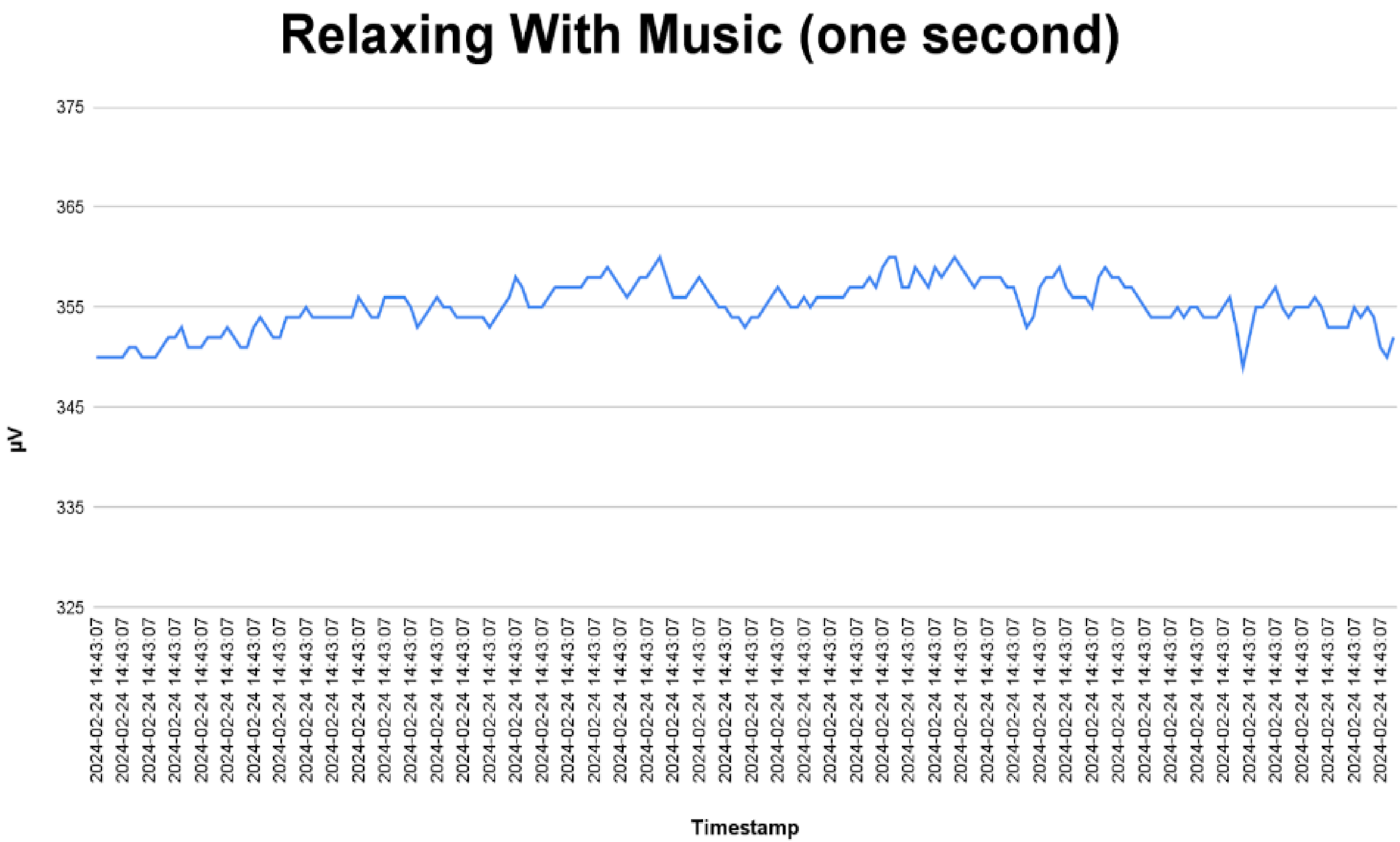
Brain-Computer Interface Python Code

```
import serial
import datetime
from time import sleep

# Open serial port device
ser = serial.Serial('/dev/cu.usbmodem142201', 9600)

# Open or create a file to log the data
with open("raw_bci_data_with_timestamps.csv", "a") as file:
      while True:
            try:

                  # Read a line from the serial port
                  data = ser.readline().decode('utf-8').rstrip()

                  # Get the current timestamp
                  timestamp = datetime.datetime.now().strftime("%Y-%m-%d %H:%M:%S")

                  # Combine the timestamp with the data
                  line = f"{timestamp}, {data}"

                  # print to console so we can see it
                  print(line)

                  # print to a file for loading into Google Sheets
                  file.write(line + "\n")
                  file.flush()

                  # delay for 0.1 seconds
                  #sleep(0.1)

            except KeyboardInterrupt:
                  print("Logging stopped")
                  break
```


Typing (one second)
375
365
355
345
335
325
μV
2024-02-24 15:03:03
Timestamp

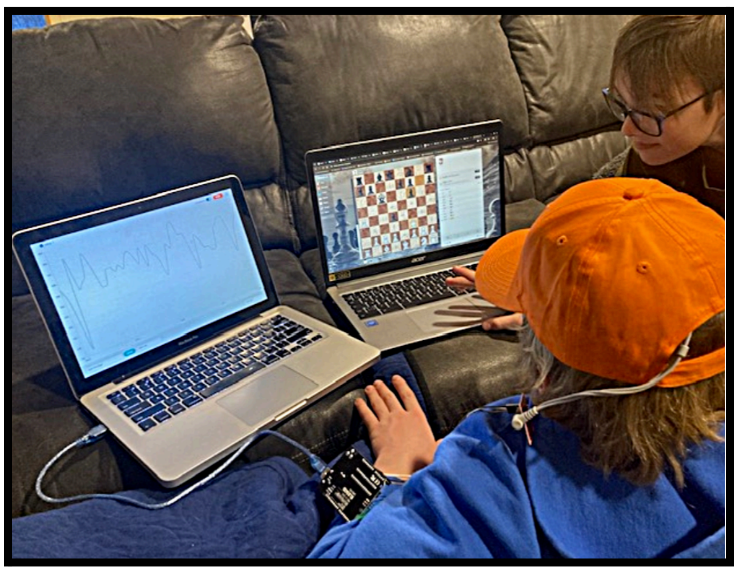

Rock Music (one second)
375
365
355
345
335
325
µV
2024-02-24 15:22:06
2024-02-24 15:22:07
Timestamp


Playing Chess (one second)
375
365
355
345
335
325
µV
2024-02-24 13:32:09


Relaxing With Music (one second)
375
365
355
345
335
325
µV
2024-02-24 14:43:07
Timestamp

Future Directions

Brain-computer interface will shape our futures; from restoring mobility to enabling telepathy, It will play a huge role in revolutionizing our modern world. Our study focused on reducing the price of brain-computer interfaces, and although we succeeded, we did not explore in-depth invasive brain-computer interfaces. Despite its lack of feasibility for a science fair project, invasive BCI will likely be the future of this electroencephalography, so an interesting study would be how to reduce the price and difficulty of that. As well as this, improving the signal processing stage will be important in ensuring its accuracy, even after reducing the price. To improve the accuracy of our model, we could have modified the AD8232 heart monitor so that it has multiple channels. This would have reduced the number of neurons each channel records, resulting in a recording more specific to the brain region we are monitoring. Finally, we will need to develop systems for interpreting the brain waves, which is important to the overall function of the device. The most accurate strategy is training artificial intelligence to understand and interpret these signals. Even the ability to interpret a yes-no response would be life-changing for patients with ALS.



Conclusion

Brain-computer interface can help people with paralysis, brain stem stroke, or spinal cord injury live a better life. Creating a more affordable version benefits low-income people who would otherwise be unable to access the technology. As well as making it more accessible to more people, it is also useful for people wishing to study the brain but not having enough funds. As financial inequality grows, having access to an affordable brain-computer interface model will become even more important. Although affordability is important, accuracy is even more important.

For this reason, we have created a model that, as well as being accessible to all, retains an adequate accuracy level. To do this, the OpenBCI ganglion board was replaced with an AD8232 heart monitor, which serves a similar purpose. We have also used fewer electrodes than usual, resulting in less advanced hardware and software. Lastly, we have used ChatGPT 3.5 to generate the code, demonstrating that people who need a BCI have a relatively easy and open-source way to acquire the software. To test our design, we recorded our brain waves while performing activities such as playing chess, relaxing, and typing. We found that as the alertness of the user increases, the frequency also rises. For playing chess, listening to rock music, and typing, the user’s brain emits gamma waves. For relaxing with music, the signals seemed more in the theta wave range.

Despite its advantages, our model only has one channel, so turning signals into computer commands may be difficult. The results of this study will change slightly across different people, so knowing how brain waves differentiate across changing populations will be vital in creating a commercial BCI that is universally accessible.

Thank you to the following people for helping me with the science fair project:

- Ms. Webber & Ms. Summerscales for teaching the science fair, and paving the way for future science fairs at Banded Peak.
- My dad, for helping to write the code that visualizes the data on Google Sheets
- My mom did several things, such as helping me edit the text.
- ChatGPT 3.5, for writing the code

  (We did this to show people who might need a BCI that you don’t need to be a software expert to create one)

Citations

Research Sources

1. National Institute of Neurological Disorders and Stroke. (2023, November 15). *Brain Basics: Know Your Brain | National Institute of Neurological Disorders and Stroke*. National Institute of Neurological Disorders and Stroke. Retrieved January 11, 2024, from https://www.ninds.nih.gov/health-information/public-education/brain-basics/brain-basics-know-your-brain
2. National Library of Medicine. (1992). *Major Structures and Functions of the Brain - Discovering the Brain*. NCBI. Retrieved January 11, 2024, from https://www.ncbi.nlm.nih.gov/books/NBK234157/
3. National Library of Medicine. (2023, August 4). *Brain–computer interface: trend, challenges, and threats*. NCBI. Retrieved January 11, 2024, from https://www.ncbi.nlm.nih.gov/pmc/articles/PMC10403483/
4. Nicolas, L. F. (2012). *Sensors | Free Full-Text | Brain-Computer Interfaces, a Review*. MDPI. Retrieved December 20, 2023, from https://www.mdpi.com/1424-8220/12/2/1211
5. Queensland Brain Institute. (n.d.). *Types of neurons - Queensland Brain Institute - University of Queensland*. Queensland Brain Institute. Retrieved January 11, 2024, from https://qbi.uq.edu.au/brain/brain-anatomy/types-neurons
6. Roy, A. (2023, July 3). *Everything you need to start building HCI & BCI Projects | Launching DIY Neuroscience Kits*. YouTube. Retrieved January 3, 2024, from https://www.youtube.com/watch?v=_dAHZdoh_kg

7. University of Calgary. (n.d.). *What is BCI? | Calgary Pediatric Brain-Computer Interface Program | Cumming School of Medicine | University of Calgary*. Cumming School of Medicine. Retrieved November 30, 2023, from https://cumming.ucalgary.ca/research/pediatric-bci/bci-program/what-bci
8. U.S. Government Accountability Office. (2022, September 8). *Science & Tech Spotlight: Brain-Computer Interfaces*. Government Accountability Office. Retrieved January 11, 2024, from https://www.gao.gov/products/gao-22-106118
9. Woodruff, A. (n.d.). *What is a neuron? - Queensland Brain Institute - University of Queensland*. Queensland Brain Institute. Retrieved November 25, 2023, from https://qbi.uq.edu.au/brain/brain-anatomy/what-neuron
10. Lingbib. (2020, August 11). *Mind Control 3: EEG Monitor: 7 Steps (with Pictures)*. Instructables. Retrieved January 4, 2024, from https://www.instructables.com/Mind-Control-3-EEG-Monitor/
11. OpenAI. (2024). *ChatGPT* (3.5) [Large language model]. https://chat.openai.com

Image Sources

1. DeVille, K. (2020, October). *Elegoo Uno R3* [website]. ARDUINO UNO VS. ELEGOO UNO – WHY KIDS WILL LOVE DEVELOPMENT BOARDS! https://stemeducationguide.com/arduino-uno-vs-elegoo-uno/
2. How To Electronics, (2022, November). AD8232 ECG Sensor [website]. ECG Graph Monitoring with AD8232 ECG Sensor & Arduino https://how2electronics.com/ecg-monitoring-with-ad8232-ecg-sensor-arduino/

3. Rehab, F. (2023, July). Prefrontal Cortex (Website). Prefrontal Cortex Damage: Understanding the Effects & Methods for Recovery https://www.flintrehab.com/prefrontal-cortex-damage/ https://www.britannica.com/summary/brain
4. The Editors of Encyclopaedia. (2003, August). Side View of the Brain (Website). Brain Summary https://www.britannica.com/summary/brain
5. Qianqian Li. (2015, September). Working of Brain-Computer Interfaces. (Website). ResearchGate https://www.researchgate.net/figure/Working-of-Brain-Computer-Interfaces_fig2_280948092
6. Marr, B. (2023, August). AI's Next Frontier: Are Brain-Computer Interfaces The Future Of Communication? (Website). AI's Next Frontier: Are Brain-Computer Interfaces The Future Of Communication? https://www.forbes.com/sites/bernardmarr/2023/08/11/ais-next-frontier-are-brain-computer-interfaces-the-future-of-communication/?sh=5763f3c951d9
7. Shankland, S. (2022, December). Neuralink, (Website). Neural ink's Upgraded Brain Chip Hopes to Help the Blind See and the Paralyzed Walk https://www.cnet.com/science/neuralink-upgraded-brain-chip-hopes-to-help-the-blind-see-and-the-paralyzed-walk/
8. OpenBCI, (n.d.). ALL-IN-ONE BIOSENSING R&D BUNDLE (Website). OpenBCI shop https://shop.openbci.com/products/all-in-one-biosensing-r-d-bundle