Vibrotactile Stimulator for Somatosensory Research in Humans Final Report

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Activity Report

Abstract—The field of Neurology is ever changing. Every day something new is learned and put to good use to research and learn more about disabilities we may know very little about in terms of treatment. That was the overarching goal of this project. To help further the research and understanding in the Somatosensory field. Which focuses on the act of sensation, and how the brain/human react to said sensory stimulations. In this report we will give a brief overview of what was accomplished in this project, how it was designed, experimentation results, future work, etc.

Index Terms—Background, Impact, Design, Experimentation, Future work

1 Background

THE field of somatosensory is the study of denoting a sensation, anywhere in the body such as pressure, pain, or warmth. For the scope of this project we will be focusing on the first item mentioned, pressure as well as vibrations. Injuries to the brain, or neurological disorders can affect how people perceive these external stimuli, and how they react to said stimuli. The goal of this project was to further the research in somatosensory, as well as see how the brain and body perceives external stimuli, and perhaps use these findings to better the rehabilitation methods of those with a neurological disability.

We did this by creating a device that targets the pointer fingertip, specifically the pacinian corpuscles, and vibrated them at a certain frequency at differing levels of pressure. Then proceeded to run psychometric (what you perceive) and neurometric (what the brain perceives) trials. With this data we wanted to be able to see what responses could be illicited, and how they could be related to further the research on what the human body senses.

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2 System Requirements

2.1 Motor Frequency

In order for us to vibrate the fingertip, we needed to get an LRA (Linear vibration motor). Now, just having the motor wasn't enough, as we also had to factor in the motor's operating frequency. The reason for this is due to the part of the finger tip that we are experimenting on. The pacinian corpuscles are the sensory nerve endings in your fingertips that deal with pressure and vibration. These receptors in the fingertips respond primarily to vibratory stimuli at a rough frequency range from 150 to 350Hz. So in order to get the best possible stimulations when vibrating the finger, we had to assure the motor's frequency was in that range.

2.2 Consistent Pressure

The level at which pressure is applied to the motor is a vital part of the project and it's ex-

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perimentation. In order to get the most accurate and consistent results, we have to assure that the participant is not simply putting a random amount of force on the motor. With the consistent pressure it will also be easier to replicate experiments with the same individuals, and eliminate additional external factors that could potentially skew the results.

2.3 Portability

Another important aspect of this project is it's portability. As the goal is to someday use this in the field with doctors and patients, we needed to make the device as small, compact, and portable as possible for ease of use. With this added portability it will make transferring the device from room to room and to different participants finger's easier.

3 System Design

For our current design, we have components working in tandem to buzz a person's finger and have the potential to record EEG waves to view brain wave activity. Starting off we have our apparatus to secure the finger snugly, to prevent it from moving during testing. From there we have the LRA motor to vibrate the finger and pressure sensor to read force output values, which will both also be in the finger cuff, stacked on one another. Controlling the motor, we have the motor driver which gives us increased finite control over the vibrations. An LCD screen to view the pressure values, in order to maintain consistency, BNC connector and LED to view brain waves through an EEG, which will be expanded upon below. And finally an EEG machine provided to us, in order to record said brain waves and interpret them.

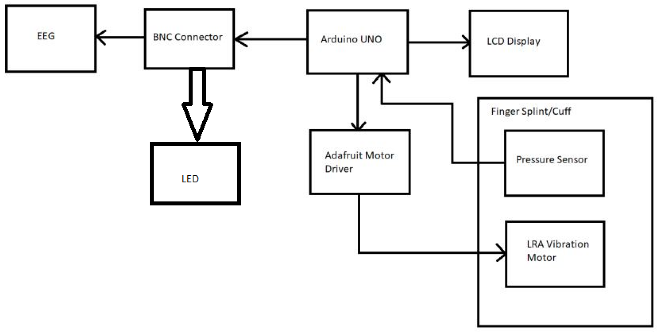

Figure 1. System Design Diagram

3.1 System Components

Below are the aforementioned components, there descriptions, and how they contributed to our final system design:

- **Finger Straightener/Splint:** This finger holding apparatus was used in order to keep the participant's finger steady and helped keep a steady pressure of the finger, as it had a knob on the top to tighten and loosen the clamp as needed.
- **LRA Motor:** Since the goal of the project is to gather information on how people react to vibrations, this motor was used to vibrate the finger at a frequency that pacinian corpuscles will be able to read easily. This will be vital when gathering experimentation data for the EEG and physical tests.
- **Arduino Uno:** In the design, the arduino acts as a controlling device for almost all the components. With the use of this micro controller we are able to relay instructions to other components that rely on it to work.
- **LCD Screen:** With the addition of an LCD screen, we were able to output values given from the pressure sensor. This was useful as we could then determine how much pressure was being applied and if it was consistent, or perhaps not the correct pressure level.
- **Adafruit Motor Driver:** Working with the LRA motor, although we had some freedom, we were dealing with limited functionality in terms of amplitude of buzzes and how often it would buzz. That's when the motor driver proved a valuable asset, as it gave us far more control of the motor. This ranged from weak to strong buzzes, how frequent they buzzed, in what order to buzz (increasing, decreasing) etc.
- **BNC Connector and LED** The BNC Connector is important because it allows for the device to be integrated along with the

EEG machine. This allows for the participants responses to be linked to the driving pulse of the motor so that the data is easier to collect and more accurate. The LED allows for the device to visually display when the motor is supposed to be vibrating and when the signal is being sent out to the EEG.

- **Pressure Sensor:** Finally we have one of the most important components as it satisfies our consistent pressure requirement, the pressure sensor. With this sensor, we can accurately quantify the amount of force being placed on the sensor, and the motor, with the help of the LCD screen as well to display said values. This will again prove to be vital for experimentation if we wish to replicate previous experiments with the same conditions, or if we wish to work with varying levels of pressure on the motor.

4 Experimental Design

Looking back on our previous Experimental Design, we went ahead and included a lot of the features which we planned to add, as well as adding some new ones which will further increase our products standards to the standards of the Stakeholder, Dr. Disha Gupta. On top of including the pressure sensor (Sensor chosen: Flexiforce A301), we also decided to implement a system of RJ11 connectors, which make it easier to swap out the motor and pressure sensor in case anything fails.

Finally, we have implemented our own custom printed PCB Arduino Shield, which eliminates the need for multiple jumper wires and the bread board. The PCB allows us to clean up our design, and move on to collecting the data for both the Psychometric and Neurometric tests.

- The research question that we hope to answer with our experiment is how the brain responds to stimuli on the tactile interface, and how those with neurological disorders could potentially react differently then those without neurological disorders.
- The data we are collecting includes a mix of Psychometric and Neurometric data, each with their own tests and importance. The Psychometric tests include placing the device on the participants finger and increasing the amplitude of the motor vibration until the participant indicates they can sense the motor. From this, we can derive a persons "Detection Threshold", which is the border to where someone can sense the vibration on the tactile interface. The Neurometric Data comes from testing the device with the EEG (Electroencephalography) machine, and recording the brain readings from when a vibration is sent to the participants finger. With the mix of this data that we are collecting, we are hoping to accurately describe what a person's brain is sensing during a pulse on the tactile interface, whether it be recognized consciously or sub-consciously. The dependent variables for this device include the pressure between the persons finger and the motor itself, as well as the amplitude of the vibration for the trial. Independent variables include the brainwaves of the participant we are measuring.
- The reason that we believe this experiment will be useful is because it gives us a closer look at the sub-conscious response to the stimulation on the tactile interface. The human sub-conscious, for lack of a better term and as put by our stakeholder, "does not lie", and gives us an accurate viewing at how a person is responding to the stimulation. We can compare the responses of someone with and without a neurological disorder to potentially discover better treatments / rehabilitation methods for treating a person with said disorder.
- The way that we are ensuring our data is meaningful and reliable is by our addition of the pressure sensor which will ensure that the motor is sitting on the participants finger at the same pressure level for the duration of the test. Another way we are controlling bias is by hiding the circuit and LED from the participant, to avoid the brain noise of what they are seeing / hearing, we only want to focus on what

they are feeling, which means eliminating as many outside distractions as possible.

5 Results

First, looking at the Psychometric results, there are bar graphs based on the tests that were run, which involved slowly increasing the amplitude of the vibration sent to the participants finger, and the participant would alert when the vibration was felt. Based on this, we created these charts to show how each of us responded to these trials. It is also worth mentioning that we did not have units when measuring the amplitude of the vibration strength. The numbers on the y-axis simply represent the vibration level as stated in the integrated arduino library when working with the motor driver.

Secondly there are the Neurometric results that were collected based on the tests we ran with Dr. Gupta using the EEG headset. The test was run utilizing a pulse at an easy to detect amplitude with a random amount of time in between each pulse, but 15% of the pulses would be of a much higher amplitude, and this is what we are interested in when it comes to the results.

Lastly to remain constant in the experimentation, the same four participants were used throughout the entire experiment labeled S1 through S4. All four participants are adult males, who were informed on the trials, and consented to the trials prior to data collection. It is worth noting additionally that S3 has a neurological disorder affecting the right side of their body, hence why they were tested twice.

5.1 Psychometric & Neurometric Data

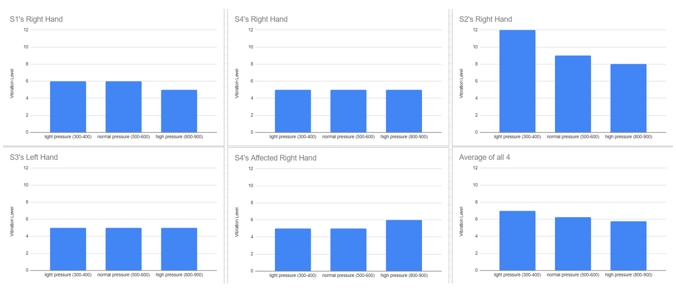

Figure 2. Psychometric Results based on Dominant Hand

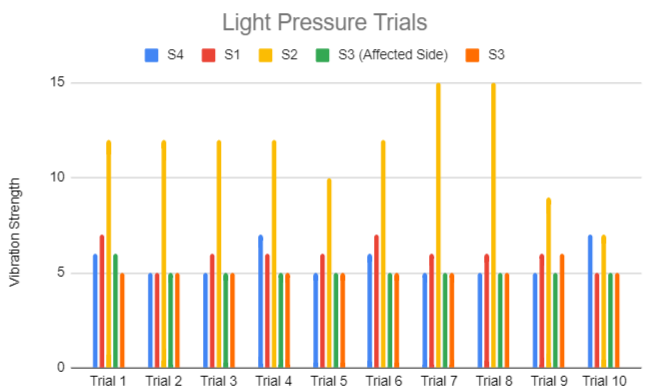

Figure 3. Psychometric Trials with Light Pressure Applied between Finger and Motor

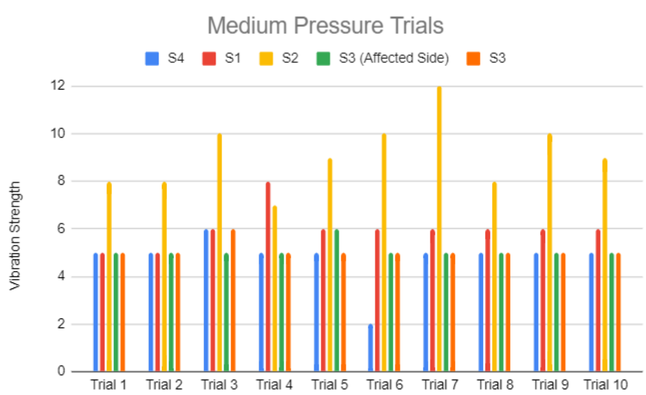

Figure 4. Psychometric Trials with Medium Pressure Applied between Finger and Motor

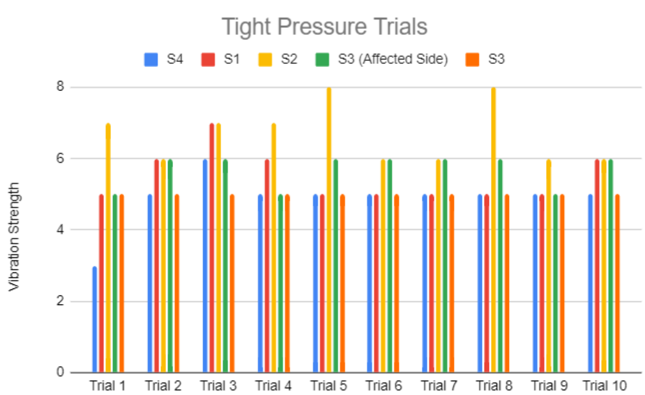

Figure 5. Psychometric Trials with Tight Pressure Applied between Finger and Motor

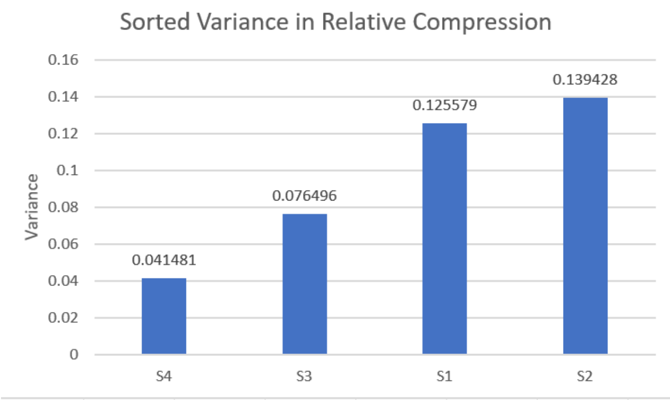

Figure 6. Sorted Variance given Compression Data (units in sigma squared)

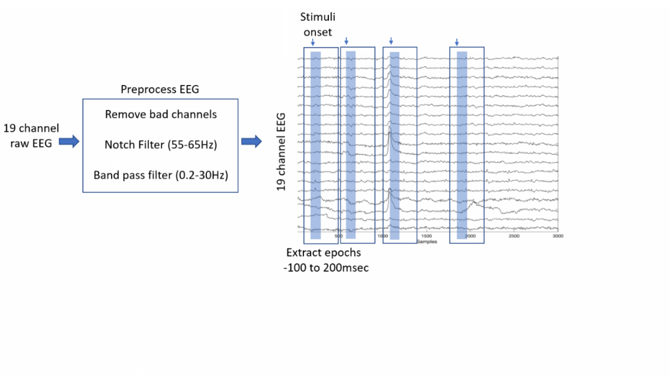

Figure 7. Data Collection Method

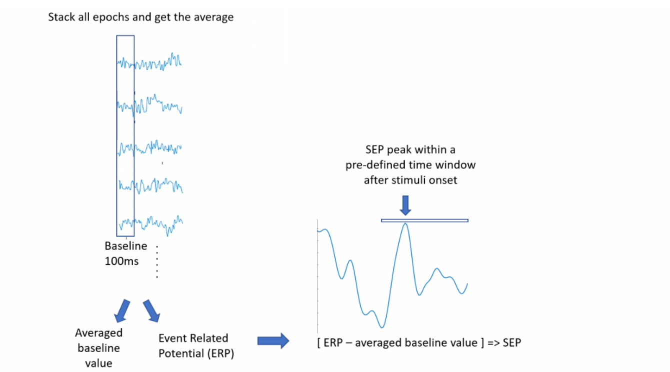

Figure 8. Capturing SEP Peak Based on ERP

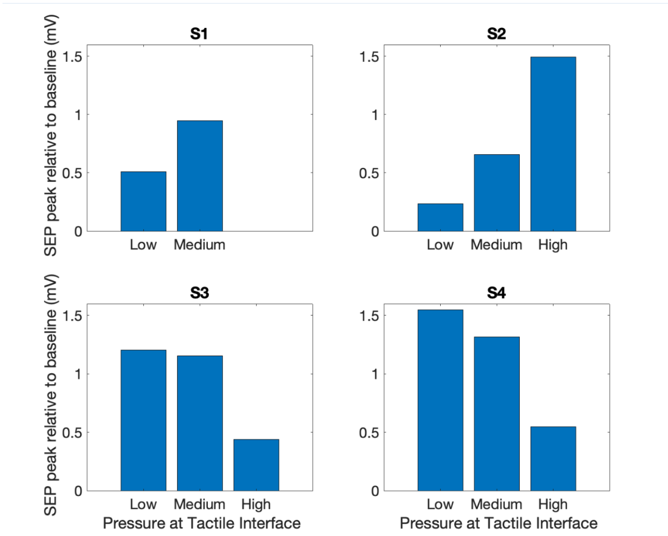

Figure 9. Results from EEG Trials

6 Discussion

6.1 Psychometric Data

Taking a look at our Psychometric data in a little more detail, we discovered some interesting things based on the trials. Figure 1 is showing how steady our responses were to a specific ”force threshold”, or the amplitude in which we started to feel the vibration. Taking a look at S4’s Right Hand and S3’s Left Hand, notice the steadiness of the bar graphs, meaning as pressure increased, S4 and S3 still felt the vibration at the same amplitude. Comparing this to S1 or S2’s data (both Right Hand), S1 and S2 would start to sense the vibration at a lower amplitude when the pressure increased, which was inline with our hypothesis of ”A participant will sense the buzz at a lower amplitude if pressure increased”. On the contrary however, taking a look at S3’s Right Hand, which is affected by the neurological disorder, the data shows to be the opposite of our hypothesis, meaning S3 sensed the vibration later then expected when pressure increased. Figures 2 - 4 show a more in depth view of each participants response to each trial, at each of the three pressure levels. Another finding worth mentioning is found in Figure 5. Both S4 and S3 had lower relative compression’s than the other two participants, meaning less overall compression change was noted when testing at different pressure levels. Interestingly S3 and S4 also had thinner fingers than the other two, leading to them needing less of a compression when trying to get to a desired value. This could potentially explain why there tactile sensation showed a stagnation whenever the pressure was increased.

6.2 Neurometric Data

When looking at the Neurometric data collected, it is important to understand what exactly is being shown. Each of these graphs, for S1 through S4, an average baseline value was captured, which would be the amplitude of the EEG wave prior to stimuli. By stacking all 19 channels of the EEG and creating an average response, we can find from these waves an ERP (Event-Related Potential), which is when the stimuli has occurred and the wave has peaked, as pictured in Figure 6. By taking our ERP captured in the window of each 100ms stimuli, and subtracting the average baseline value from this, we come out with each participants SEP (Somatosensory-Evoked Potential), which is the brains elicited response to the stimuli on the tactile interface, as pictured in Figure 7. By averaging out all of the SEP values collected for each participant in each pressure level, and comparing those to the baseline, we come up with the charts as pictured in Figure 8. Please note, that participant S1’s high pressure trial was done in a different threshold compared to participants S2 - S4, so it has been omitted. Taking a look at participants S1 and S2, we notice that their SEP peaks trend up as pressure increases, meaning the brain elicited a greater response to the stimuli as pressure between the motor and finger increased. Comparing this to our Psychometric results, this directly follows our hypothesis that as pressure is increased, the participant would elicit a greater response to higher amplitude stimuli, due to them being able to sense the stimuli clearer. However on the contrary, looking at participants S3 and S4, their SEP peaks trend down as pressure increased, meaning their brains elicited a smaller response to the stimuli as pressure increased. This runs in direct contrast to our hypothesis, however, it does open the door to some discussion about how finger thickness can play a huge role in determining how pressure affects your response to stimuli on the tactile interface, as it is important to mention that participants S3 and S4 have much thinner fingers when compared to participants S1 and S2.

6.3 Limitations & Future Work

- **Recommendation 1:** A big aspect of this project is reading consistent pressure values in repeated experiments, to keep things constant. Although we could roughly mark how much to tighten the finger splint apparatus to get a desired reading, it wasn’t an exact science. Everything factored in this reading, from thickness, how the finger was placed to sweat levels. In order to combat this, we would ideally want to implement a more accurate way to hold the finger and read values.

Something that could be controlled with computer values, to get the exact same level of tightness each time.

- **Recommendation 2:** A Limitation we found ourselves working around quite frequently was the lack of precise control we had over the motor's pulsation amplitude. While we still had a few levels to play around with and could control the vibration levels somewhat, it would have been ideal to test with more vibration levels at different rates in order to get a better scope of what vibrations were the just the right amount, not overly strong or weak. This could be done in the future by buying a more advanced motor driver that could support more functionality.
- **Recommendation 3:** One other limitation that comes to mind when dealing with this project is portability. Ideally we want the project to be as small and lightweight as possible, in order to be portable for different patients. The way the project is set up now, the Arduino has to be plugged into a laptop for both power and the code uploads. To address this in the future, a battery could be added to the Arduino to provide an external power source. This would make the project more standalone and less reliant on other factors.

7 Conclusion

When we look at the project as a whole, our initial problem to solve was to build this device to measure the response to stimuli on the tactile interface. The requirements of the system, as laid out by our stakeholder, were to improve upon her current design by adding an increased sense of accuracy and modularity to our implementation. By adding one of our key components, the pressure sensor, we were able to achieve success in making the system more accurate between trials, and on top of this, discover and work with the idea of a participant's "force threshold" for different pressure values, and how these would affect the results of our experiments. As for the aspect of modularity, to achieve this we decided to custom print a PCB shield to go on top of our microcontroller, and place the device in a custom printed 3-D enclosure. By doing this, we have increased the portability of the device, allowing it to be used in many different locations and decreasing the set-up time and labor of the device as a whole. Secondly, on the matter of modularity, our addition of the RJ-11 connections has greatly increased the ease of swapping out both the motor and pressure sensor, in the case that one should fail.

Overall, the main goal of this project is for research in Somatosensory in humans, with the hope that by measuring the brains response to stimuli on the tactile interface, a breakthrough could be made to help better rehabilitate and treat those with neurological disorders.

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