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Final Prototyping Memo: E.W.A.

BACKGROUND:

Dr. Shannon Burns is in charge of a neuroscience lab at Pomona College that uses Functional Near Infrared Spectroscopy (fNIRS) to study brain activity in response to visual stimulation. fNIRS is a neuroimaging method that uses infrared (IR) light to detect changes in concentrations of oxygenated hemoglobin (HbO) underneath the skin. This technology works by projecting IR light into the scalp via "source" optodes. This light passes through human skin and bone but is differentiably absorbed and/or scattered by HBO in the bloodstream. Nearby "detector" optodes located approximately 3cm from their corresponding source optodes, measure the amount of light reflected out of the head, giving the current concentration of HbO at the intervening area. There are a total of 64 optodes, with 32 source and detector pairs.*(See figures 3-5)* The optodes are held in place by plastic mounting bases that are secured in a stretchy mesh head cap that the subject wears. Moreover, the optodes are organized according to the 10-20 International System and are individually fastened to their mounting bases by plastic spring casings (Figure 1).

Figure 1: Optodes are held in place by plastic mounting bases according to the 10:20 International System and are fixed to the cap by washers inside the cap. The red tags indicate mounting bases for source optodes, while the blue tags are for detector optodes.

For fNIRS to measure brain activity, sufficient IR light must be projected into the scalp. For this light to reach beneath the skin, the source and detector optodes must make contact with the scalp. Hair can create a physical barrier to this contact and impede infrared signals. In subjects with fine, thin hair, there is little obstruction. However, thicker, darker hair blocks optode access to the scalp and absorbs too much IR light to obtain a clear measurement of cerebral HbO levels (Figure 2) This difference in phenotype results in systematic underrepresentation of black, Latino, and Asian populations in neuroscience literature.

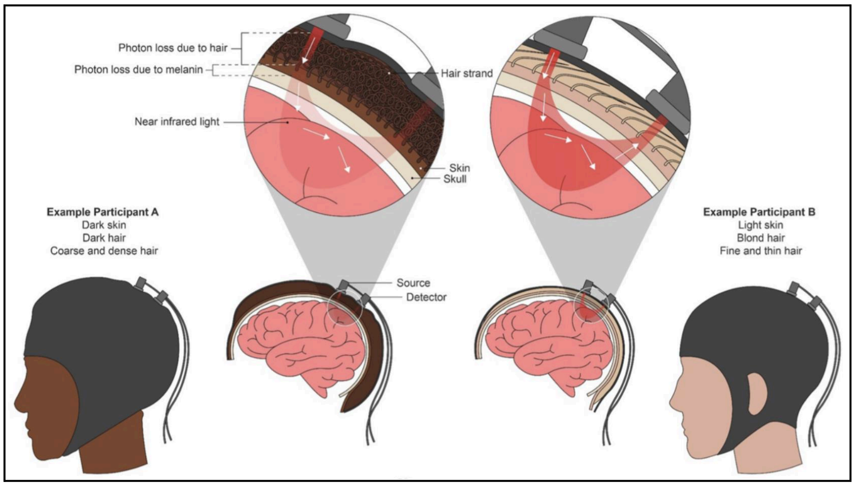


Figure 2: If IR light is blocked by dark and/or thick hair, less is projected into the scalp and less is detected upon return, reducing signal strength and data quality in patients with this phenotype.

PROBLEM STATEMENT:

There has been difficulty using fNIRS with subjects who have thicker or darker hair where the bulbs are blocked from making contact. Dr. Burns is looking for a way to direct infrared light from fNIRS to the scalp of patients with thicker or darker hair.

OPTODE DIMENSIONS:

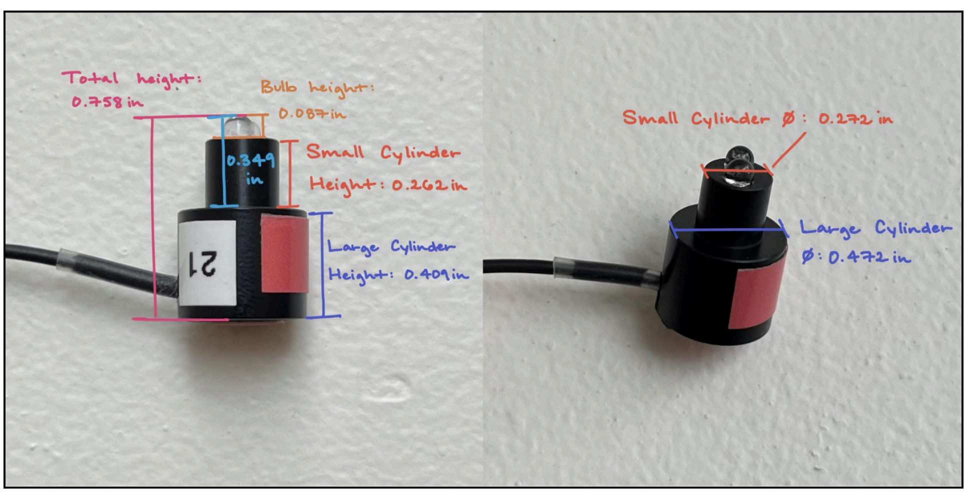


Figure 3: Side profile and dimensions of the source optodes.

Figure 4: Side profile and dimensions of the detecting optodes.

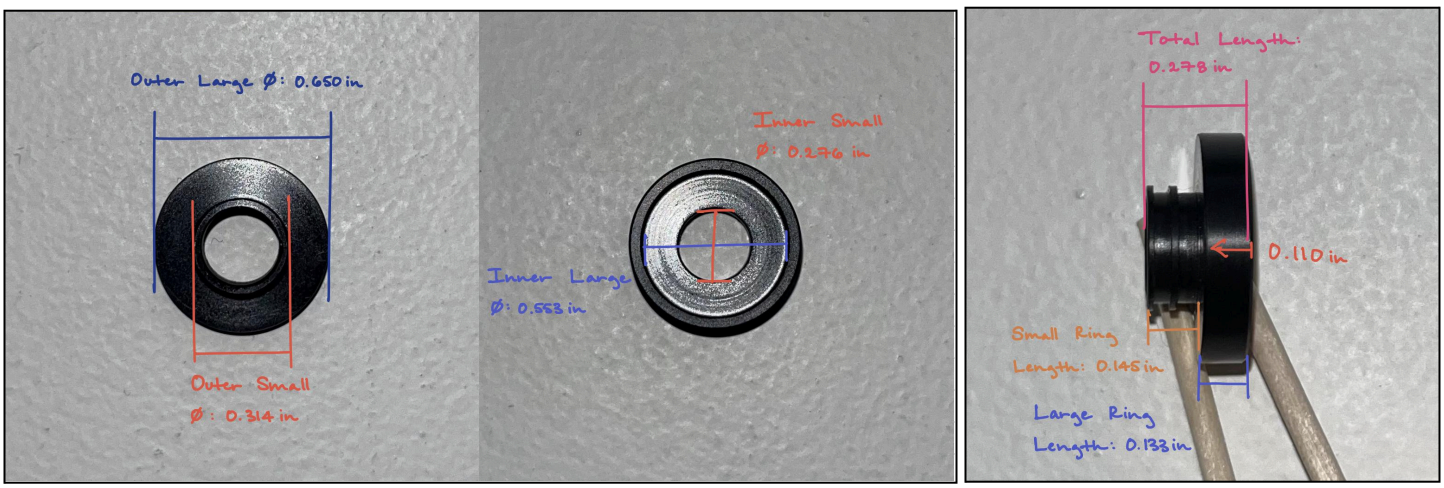


Figure 5: Dimensions of the back (left) and front (middle) profiles of the mounting base. Side profile (right) of the mounting base and dimensions.

EXPERIMENTAL QUESTIONS:

- Does keeping the black rubber casing on the fiber optics improve the ability to **thread** through hair?
    - The use of fiber-optic rods will direct the infrared light through the subject's hair and deliver it to the scalp. The thin diameter of the fiber-optic rods will guide it through the space between the hair that the current larger optode bulb cannot reach. Having fiber optics that are enclosed in the black rubber casing keeps the integrity and quality of the fiber optics so they do not get damaged or bend when in use, but may sacrifice the threading capability. Having exposed fiber optics increases the threading capability through individual strands but may cause leaking of infrared light, weakening the received and emitted signals. The results of this test will determine which option is more effective for creating an optimal signal.

- Between the gingival stimulator and the wooden dowel, which tool **moves** hair out of the way more effectively?
    - The current tool used to assist the optode in reaching the scalp is a wooden dowel. The dowel is used to part the hair within the space the optode is measuring, clearing hair out of the way to allow the light to reach the scalp. However, it may not be the most effective method. This test will attempt to utilize a different tool in the shape of a gum stimulator to see which is more effective in moving hair out of the way and clearing the scalp for the optode. The results of this test will provide a secondary option of a tool that the client can utilize when testing.
- What is the most effective way to **apply** increased pressure to the optode to reach the scalp?
    - One of the main issues with the fiber optic prototype was that sufficient pressure on the optode and fiber-optic rod was not being consistently applied. This was due to the hair pushing up against the cap lifting everything up. When there was sufficient pressure, the data was clearer and when the pressure was relieved, the data became noisy and unusable. The prototype was creating a mounting base with an increased diameter, allowing the fiber-optic rod slide through the base to penetrate deeper into the hair than the current diameter allows. The results of this test will determine if the widened mounting base is a more effective way to apply increased pressure to the optode.

PROTOTYPING:

These prototype designs will be shared in the following descriptions. :

1) Fiber Optics Attachment & Custom Spring Cap,
2) Hair Moving Pick,
3) Custom Mounting Base

Fiber Optics:

The fiber optic attachment is designed to connect to the small cylinder of the source and detecting optodes to enable the transportation of IR light between the optode and the scalp. The materials for the fiber optic attachment include: 1) 64 0.25mm of fiber optics encased in black rubber and 2) Small black rubber caps with an inner diameter of 0.25 inches. The small black rubber caps are fit to the size of the small cylinder of the optodes (of equal small cylinder diameter) in order to create a tight fit that will not fall off and can still be flexible enough to easily be removed by hand. Furthermore, the dark color of the rubber caps prevents IR light from leaking.

There are two forms of fiber optic attachment: 1) Exposed Fiber Optics (Figure 3) and 2) Encased Fiber Optics (Figure 4). The purpose of the exposed fiber optics was to allow the fiber optic rods freedom to thread through the hair to reach the scalp. After initial testing, detailed in the Low-Resolution Prototyping Memo, it became clear that the rods were too flexible and would bend instead of thread when pressed against the hair. As a result, the encased fiber optics were designed to ensure that the fiber optic rods are well supported as a bundle. As a bundle, the fiber optics can thread through hair more easily that the original optode due to having a narrower overall diameter, yet are sturdy enough to not flex out of place when facing contact force from the scalp.

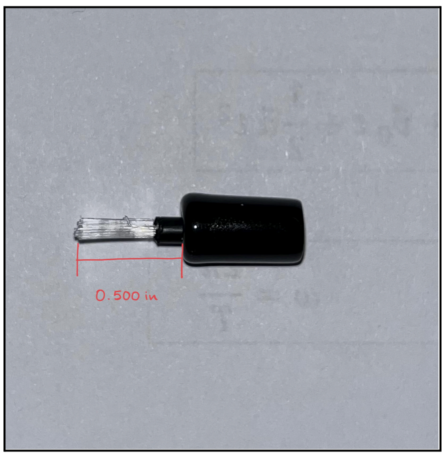


Figure 6: Exposed fiber optic attachment (left).

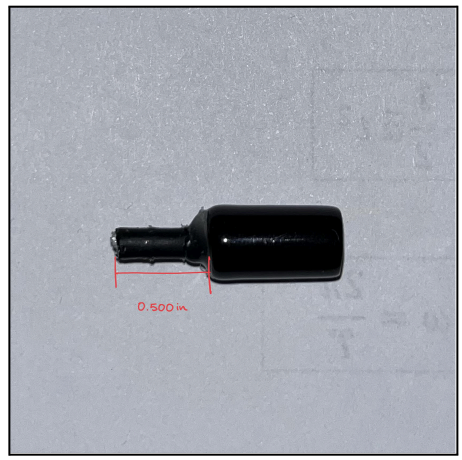


Figure 7. Encased fiber optic attachment (right).

From the Low-Resolution Prototyping Memo, the optimal length for threading ability and comfort was between 0.400 and 0.600 inches. Therefore, the length of the fiber optics outside the rubber cap is 0.500in to optimize these two objectives. Moreover, the fiber optics are attached to their rubber caps via hot glue so that they stay in place. Since fitting the fiber optic attachment around the face of the optodes widens the diameter of this part such that it is no longer able to pass through the mounting base, the optode now sits higher above the mounting base than it originally did (Figure 5). Due to the constraint at the time of "Not altering any of the 64 plastic mounting bases," an alternative, taller spring cap was originally created (Figure 6). This custom spring cap is compatible with the original plastic mounting bases provided by the client, except has a length of 1.475in to account for the displacement of the optode from its original position through the plastic mounting base. The spring cap is an essential component to the data collection system because it keeps the optodes held down against the mesh cap on the user's head, therefore creating pressure to maintain the pathway between the IR light and the scalp.

Figure 8: Optode with attachment cannot pass through the inner hole of the original mounting base (right).

Figure 9: Taller custom spring cap (left).

Hair Moving Pick

The goal of the hair-moving pick was to improve on a current solution. Currently, the tool used is the end of a wooden dowel to move hair out of the way, an ineffective method because it is unable to catch hair to push it out of the way. The hair-moving pick (Figure 5) has an attachment in the shape of a hook that is able to catch on the hair and gain enough leverage to push it out of the way (Figure 6). The hair-moving pick is made from an existing dental tool, a gingival stimulator. The change in the design is the removal of the rubber pick at the end of the tool, leaving a dull metal hook.

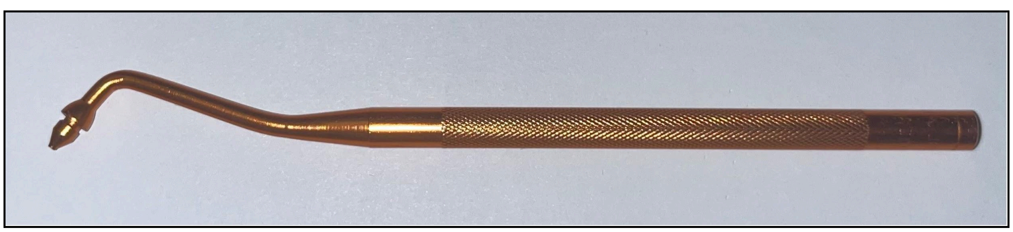


Figure. 10: Pick with the tip removed (left).

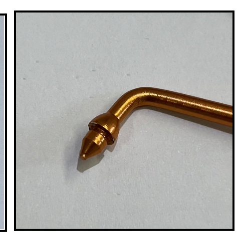


Figure 11: Isolated pick head (right).

Custom Mounting Base

The custom mounting base (Figure 9) is designed to enable the optode to fully slide through the base, addressing the issue of insufficient pressure to hold it down securely. It is paired with a new washer (Figure 10) to secure the base into the cap. This custom mount replicates the original design but features a wider inner diameter to prevent the optodes from getting stuck on the ridges along with a slit to allow the wire of the optodes to pass through. The spring cap is then employed to press the optodes down lower, ensuring contact with the scalp even if the cap is pushed up by the hair. This was achieved by creating a part in SolidWorks and 3D printing it using PLA carbon fiber filament.

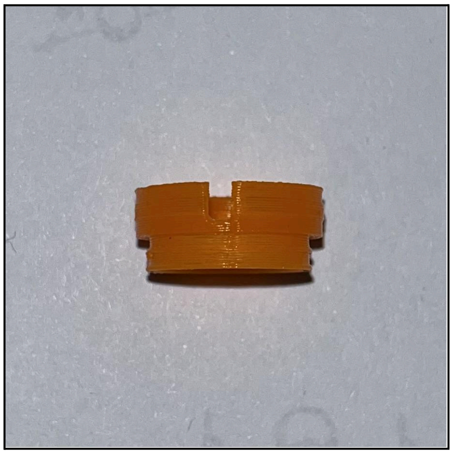


Figure 12: Custom mounting base with slit (left).

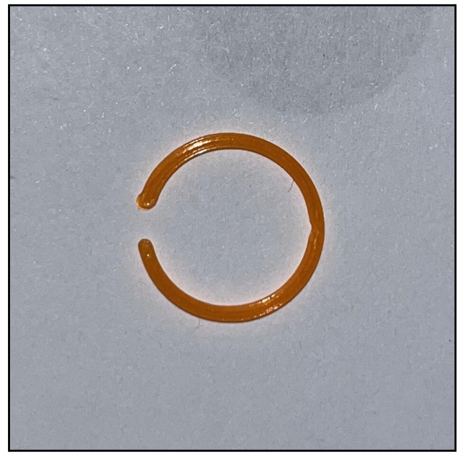


Figure 13: Snap-in washer (right).

EVALUATION PLAN:

To evaluate the effectiveness of our final prototype, three tests of signal coloration and cleanliness were conducted with three different prototypes. The protocol was conducted as similarly as possible for our three tests to ensure that each experiment was controlled. The design is targeted towards accommodating subjects like Gabrielle Reynolds, a black student with thick and textured hair [Hair Type: 3C, 4A]. The following experimental procedures are conducted with prototypes that are designed for those with similar hair types as Gabrielle.

Fiber Optics and Spring Cap: *Experiment Protocol*

1. Secure the mesh head cap on the mannequin's head.
2. Place 3 pairs of optodes into their designated locations (10-10, 15-15, 18-18) and fasten them in place using the snap-in spring casings.
3. Remove the mesh head cap with the fastened optodes from the mannequin's head and carefully secure it to the subject's head.
4. Turn on the MatLab software and open to the digital map of the 10-20 International System that corresponds to the optodes in the mesh head cap.
5. Take an initial reading of the subject's HbO levels. Take note of the coloration of each optode signal on MatLab. Red indicates a poor signal, Yellow indicates Adequate signal, and Green indicates Excellent signal.
6. Once the initial signals have been noted, begin testing by removing the spring casings for the optodes. Replace it with our fiber optic attachment and redesigned spring cap and allow the signal to run.
7. Read the updated HbO levels in MatLab and note the signal coloration changes.

Hair Moving Pick: *Experiment Protocol*

1. Secure the mesh head cap on the mannequin's head.
2. Place 3 pairs of optodes into their designated locations (10-10, 15-15, 18-18) and fasten them in place using the snap-in spring casings.
3. Remove the mesh head cap with the fastened optodes from the mannequin's head and secure it to the subject's head carefully.
4. Turn on the MatLab software and open to the digital map of the 10:20 International System that corresponds to each optode.
5. Take an initial reading of the subject's HbO levels. Take note of the coloration of each optode signal on MatLab. Red indicates a poor signal, Yellow indicates Adequate signal, and Green indicates Excellent signal.
6. Then, remove the spring casings and the optodes.
7. Using a wooden dowel, carefully push hair to the sides until you can see the subject's scalp through the mounting base. Snap-in the spring casing once complete.
8. Read the updated HbO levels in MatLab and look for signal improvement.
9. Run the process again starting from step 7, but instead using the second tool, the gingival stimulator with the rubber tip removed and compare the signal from both tools.

Custom Mounting Base: *Experiment Protocol*

1. Secure the mesh head cap on the mannequin's head.
2. Place 3 pairs of optodes (source and detector) into their designated locations (10-10, 15-15, 18-18) and fasten them in place using the snap-in spring casings.
3. Remove the mesh head cap with the fastened optodes from the mannequin's head and carefully secure it to the subject's head.
4. Turn on the MatLab software and open to the digital map of the 10-20 International System that corresponds to the optodes in the mesh head cap.
5. Take an initial reading of the subject's HbO levels. Take note of the coloration of each optode signal on MatLab. Red indicates a poor signal, Yellow indicates Adequate signal, and Green indicates Excellent signal.
6. Once the initial signals have been noted, begin testing by removing the spring casings for the optodes. Replace it with our fiber optic attachment and the redesigned mounting base and allow the signal to run.
7. Read the updated HbO levels in MatLab and note the signal coloration changes.

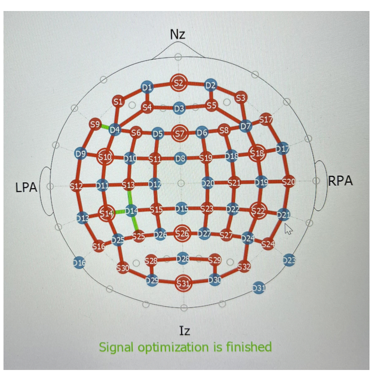
EVALUATION:

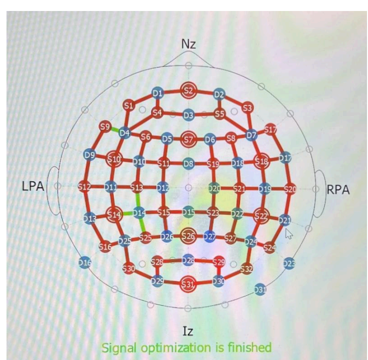
The results of the prototype testing showed that the Hair Moving Pick was successful in achieving the client's goal of improving the signal clarity in subjects with dark, thick, and textured hair, but that the Fiber Optic Attachment & Custom Spring Cap and Custom Mounting Base methods were not. The responses to the experimental questions and analysis of these prototype methods will be shared in the following descriptions.

Fiber Optics and Spring Cap

Does keeping the black rubber casing on the fiber optics improve the ability to ***thread*** *through hair?*

The results of our testing showed that neither of the two options of fiber optic rods, either encased or exposed, was successful in achieving the overall prototype goal of improving signal clarity. The first step in testing was getting an initial control reading that used the original optodes and spring caps. The results of the reading showed an overall red signal in the 3 optode locations that were used (Figure 14). Once the control signal strength was noted, the next step was to use the exposed fiber optic rod, attach it to the optode, and run the reading again. The result of the exposed fiber optic rod showed there was no improvement in the signal clarity and the data was still unusable (Figure 15). Then, moving to the third test, the encased fiber optic rod was used, following the same steps to test it. The results of the third reading also showed there was no improvement in the signal clarity and the data remained unusable (Figure 16). Testing the prototype showed there was no success with either fiber optic rod attachment and revealed an underlying issue with the prototype. This issue is managing the application of a consistent, sufficient pressure on the optode, allowing it to touch the scalp without being deterred and pushed back by the subject's hair.





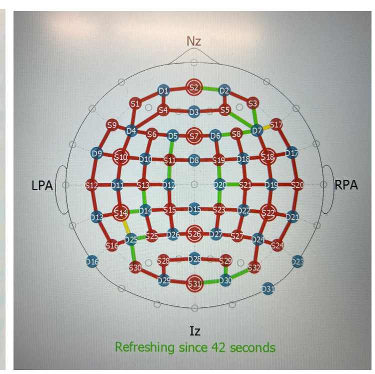


Figure 14: (Left) Reading using the original optodes and spring caps showed critical, red signals at optode intersections 10, 15, and 18.

Figure 15: (Center) Reading using the exposed fiber optics showed critical, red signals at optode intersections 10, 15, and 18.

Figure 16: (Right) Reading using the encased fiber optics showed critical, red signals at optode intersections 10, 15, and 18.

Hair Moving Pick

Between the gingival stimulator and the wooden dowel, which tool ***moves*** *hair out of the way more effectively?*

The results of our testing showed that the hair moving pick was the most successful in increasing the signal clarity of the data. During testing, the first step was to run an initial reading on the subject, using the original optodes and the current tool, a wooden dowel, to move the hair out of the way in the space under the optode. The initial reading showed that the waves were all over indicating lots of noise. Meaning that the infrared light was being blocked and was not effectively reaching the scalp. The next step was to remove the optodes and use the hair moving pick as the tool instead. Looking at the change the waves showed a significant improvement in signal quality, eventually turning from a red to a yellow signal (Figure 17). This led to the conclusion that the use of the hair moving pick is a more effective way of clearing a path through hair to deliver light to the scalp.

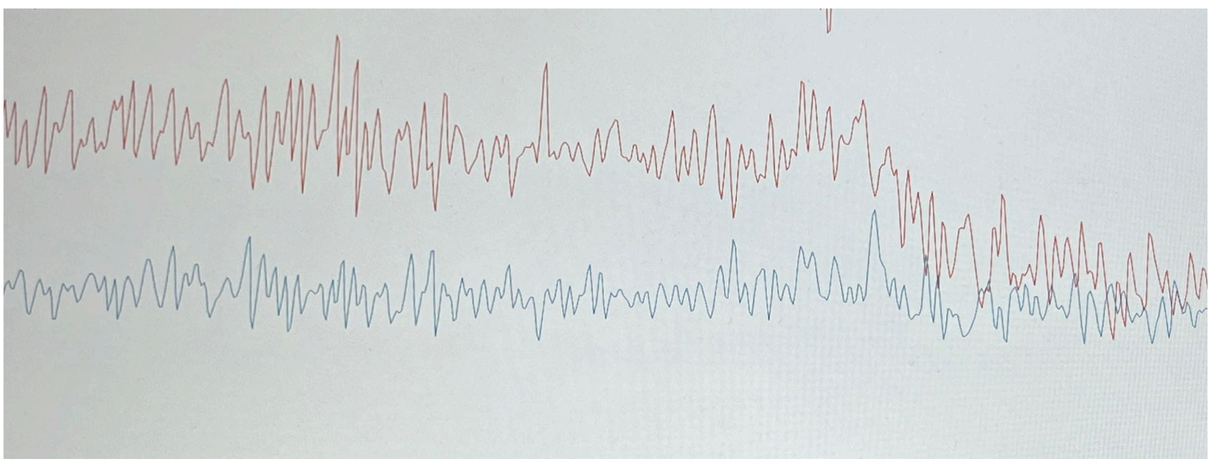


Figure 17: The stacked line plot for the 18 optode pair showed that the reading became clearer after applying the hair-moving pick.

Custom Mounting Base

What is the most effective way to ***apply*** *increased pressure to the optode to reach the scalp?*

The results of the testing showed that the custom mounting base with the widened base diameter was unsuccessful in achieving the overall prototype goal of improving signal clarity. The first step in testing was getting an initial control reading using the original optode and mounting base. Once the test was run, the reading showed that the optodes were red, meaning they had poor signal and the optode was not touching the scalp. Upon attempting to begin the next test with the custom base, another problem was discovered. With the wider diameter, the bottom of the custom base was unable to fit in the slot of the original mounting base, meaning it was rendered unusable. Therefore, the testing of the prototype had to end there because cutting a wider hole would violate the design constraint of not damaging the cap.

CONCLUSION

As a result of the testing and final prototype designs, there is a future direction that can be explored. This possibility comes from the custom mounting base prototype that involved widening the diameter of the mounting base. The result of this prototype was inconclusive, due to the design constraint of not damaging the cap, meaning that the base of the custom mount was unable to fit through and could not be tested. However, with further research and justification, the client would be willing to allow the cap to be altered, meaning more testing and modifications will be necessary. Along with the prototype, the implications for future subjects in this research is promising. Since the current prototype is targeted towards subjects with hair like Gabrielle, these slight improvements are more meaningful because there are currently no solutions for this, leaving out a large group of people. Being able to include a wider demographic of people in this research will make these studies more inclusive.