

## **Transcranial Magnetic Stimulation Positioner**

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*Abstract: The use of TMS to study the memory processes of the brain has resulted in a need for an accurate and precise positioning system relating the position of the head to the TMS holder. This is done in order to guarantee specific stimulation of a brain region in varying testing environments. The positioning system will need to be sensitive to size constraints, compatible with fMRI and EEG scans, and comfortable for the subjects participating in the experiment.*

## **Background**

### *The Study of Memory Formation*

In general, memory can be broken down into different forms: declarative and procedural. Declarative memories are formed by events in everyday life, while procedural memories are formed by conditioning (Benner). The mechanisms that control short-term memory are located in the frontal lobe while those that control long term memory are found in the hippocampus. Short term memories form quickly but also decay quickly, while long term memories have a large capacity and decay slowly (Campbell and Reece, 2002). The difference between the two lies in the idea that the synaptic connections between neurons are flexible. The connections that produce short term memories leave no structural changes, but the connections producing long term memories change the neural structure (Benner).

Neural structures can be changed by habituation, sensitization, and long-term potentiation (LTP). Habituation refers to neurons forming pathways, weakening the synaptic connections and thereby reducing the input required to transmit signals. Sensitization occurs in an opposite manner but yields a similar result. It strengthens the connections with serotonin to create a set path. LTP, unlike habituation and sensitization, involves the creation of a protein. It is the result of neurons being subject to repeated inputs, allowing them to fire for long periods of time (Benner).

### *Transcranial Magnetic Stimulation (TMS)*

TMS is a method of inducing pulsed magnetic fields into the brain. Past efforts to change the electrical potential in portions of the brain required high voltages and allowed for little accuracy. However, in order to affect the neurons inside the head, a large

amount of magnetic force is required. The technology required to do this has only been around for the past decade. This technique is non-invasive and is seemingly free of serious side effects (Kirkcaldie).

The nerve cell membrane supports a potential difference that can be changed by an externally applied electric field, depolarizing the membrane and activating an action potential. The time-varying magnetic field of this stimulation induces a current flow in these tissues (Ruuhonen). Three examples of coils can be seen in Figure 1. In the figure (a) and (b) are both O shaped coils, while (c) is an 8 shaped coil, similar to the one being used in this project.

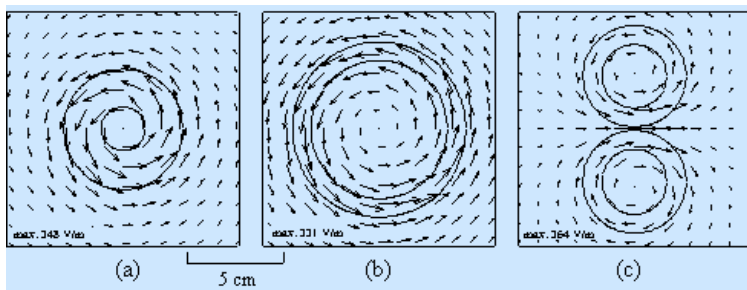


Figure 1.  
TMS Magnetic Field Diagram (Ruuhonen).

### EEG and fMRI

Typically TMS is accompanied by an Electroencephalogram (EEG). Electrodes are placed on the scalp over specific regions of the brain to detect and record patterns of electrical activity. Between 16 and 25 of the electrodes are connected to an amplifier (the signal is typically received at 100  $\mu$ V) and a recording machine. Some localization may be achieved by recording from a single electrode and comparing it to the average of all electrodes (Webster, 2004).

Magnetic resonance imaging (MRI) is a technique which provides two-dimensional slices of the body which are then combined to give a three-dimensional image. An MRI machine contains a very strong magnet on the z-axis that is able to detect the charge on  $^1\text{H}$  isotopes and process the orientation of their spin (Webster, 2004). Functional MRI (fMRI) is a more advanced MRI system used for determining which parts of the brain are activated by different types of physical sensation or activity. It is designed to pick up increased blood flow to the activated areas of the brain.

### Motivation

Previous experiments have extensively investigated memory formation. Though the use of TMS is relatively new (the past 2 decades or so), it is in common use by researchers. Our client would like to first map the “hot spots” of the brain which are functioning during the formation and recollection of memory using the EEG and fMRI scans. They would then like to stimulate these previously identified “hot spots” of the brain with TMS, essentially occupying these portions of the brain so that they cannot assist in the formation and recollection. This experiment is unique because of the need to use TMS in both EEG and fMRI conditions. fMRI is very accurate in its depiction of the brain, meaning it has a high resolution; however, fMRI is quite slow in its image formation due to the many images taken and compiled. The process may take minutes to complete an image of the brain. EEG on the other hand is much more rapid in its image acquisition, but it has a much lower resolution than the fMRI machine.

In our client’s experiment, measurements must be made by both EEG and by fMRI, each with its own specific testing apparatus. A portion of the experiment requires the TMS unit be inside of the fMRI tube with the subject. The EEG may occur up to two

weeks later and takes place in a different setting. By the nature of the experiment, the TMS unit has to be positioned in the same spot for both portions, so our client has contacted us about designing a head positioner to make sure the head is always in the same location at each testing environment.

Our client has provided us with a TMS holder (as seen in Figure 2), which is used to hold and position the TMS coil. Since the TMS holder

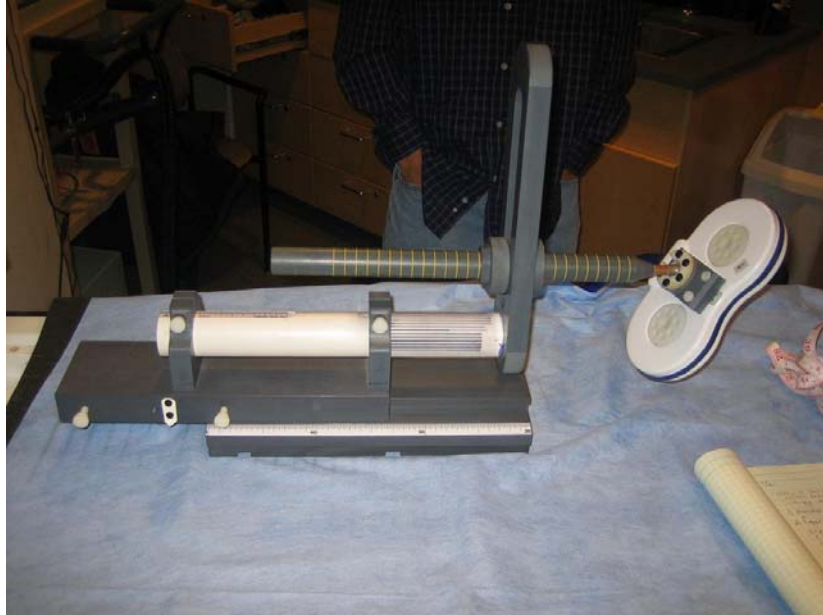


Figure 2.  
TMS Holder Client has Provided.

will be in a standard position in all locations, it will be incorporated into all of our designs.

### **Design Function:**

The experiments our client wants to perform require a device which can accurately and precisely position a subject's head with respect to the TMS holder while meeting a number of functional restrictions. These restrictions are due to multiple experimental locations, multiple subjects who vary in physique, and differing experimental apparatus, to name a few. Our design must address each of these problems in order to create a completely useful device. The positioning device must be compatible with multiple experimental locations. One experimental site is in Research Park where

the TMS will be used while a subject is also undergoing an EEG test. The other site, which will be combining an fMRI scan with TMS, is on campus, a notable distance away. Therefore, mobility of the device and the ease of setup at each location will be integral in the device design.

Our clients' experiments require both tests to be done on numerous subjects with time elapsed between tests ranging from less than one day to up to weeks later. Our design must account for varying body sizes, most notably head and neck sizes. There must not be any lasting physical effects on the subject induced by the positioning system, the subject must be comfortable, and sterility of the device from subject to subject must be addressed.

Since TMS is being performed in either EEG or fMRI settings, compatibility with the test equipment is needed. Both the EEG and the fMRI have constraints with which our design must comply. The EEG requires the subject to wear a tight cap with electrodes attached to it and various cords running over the entire head. The fMRI has a cage-like apparatus called the "birdcage" which surrounds the subject's head while they are in the scanner. The design of the positioner must not interfere in any way with either the EEG or the fMRI.

Specific areas of the brain need to be stimulated for our client's experiment. There are three specific brain regions located around the head. The head positioning system must enable the TMS to reach each of these positions and be accurate within 1 cm.

In order to prevent interference with other tests, the positioner's material must be compatible with the fMRI and EEG scans. Since the fMRI uses a strong magnetic field,

only non-metal or non-ferromagnetic materials must be used. The materials must also be durable and sturdy to undergo many tests.

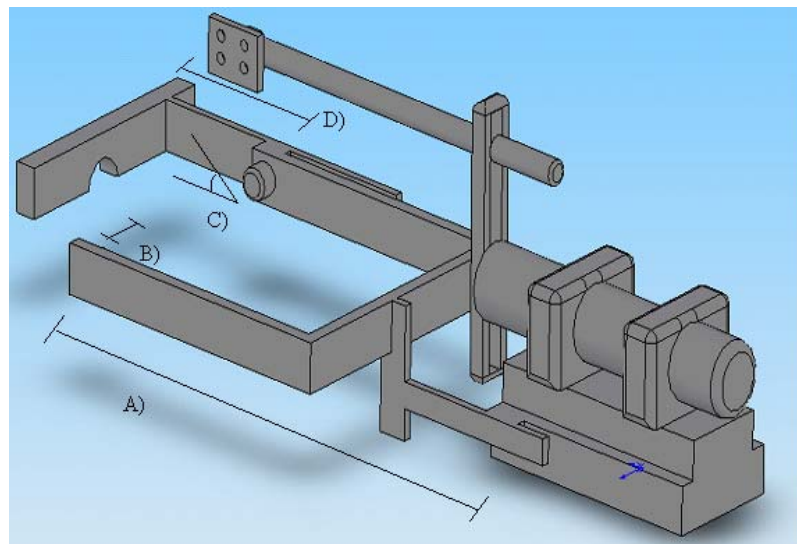
In response to our client's problem we developed the following three designs ideas. While the overall approach to accomplishing the project requirements are similar, each design has unique methods in which this is done. The three designs have been named the All-In-One Positioner, the Neck Positioner, and Head Plate.

### **Alternative #1 All-In-One Positioner**

#### Overview

The All-In-One (AIO) design utilizes the position of the TMS holder to achieve maximum levels of precision and accuracy relative to the subject's head. The AIO

design allows precise positioning of the subjects head in the MRI machine while at the same time allowing the subject a small amount of



comfort. The positioner will be made out of an MRI

Figure 3.  
Diagram of All-In-One Positioner.

compatible material which must also be durable.

### Operation

The subject must be inside the MRI machine before the All-In-One will be positioned. The setup begins with the mounting of the AIO positioner to the TMS holder. The positioner will be attached to a sliding mechanism on the bottom of the holder, thus allowing the practitioner to move the positioner to varying depths in the MRI tunnel. Once inside of the MRI machine the subject will either be lying face up or face down depending on the position the TMS needs to reach.

If the subject is laying face up, the subject's head will rest in the MRI machine with the rectangular area of the positioner on the outside of their head. If the subject is lying face down a type of massage pillow will be inserted into the machine allow the subject more comfort. The rectangular area of the positioner will again be on the outside of the subject's head.

Once the subject's head is resting comfortably inside of the machine and is lying face up, the ear plugs will be inserted into his or her ears. The depth of the ears inside the cage will be recorded using a built in measuring system on the side of the holder (as seen in Figure 3 as measurement A). The distance from the side of the rectangle to the ear will be determined using a scale built in on the sides of the ear piece extensions (measurement B). The bar above the rectangle will be used for stabilization once the subject's head is static within the structure. The final step of the setup is the positioning of the nose piece which will lie on top of the subject's nose. The bar, which is an appendage of the ear piece extensions, will have multiple scales built in to determine the position of the nose relative to the holder. The first will indicate the distance from the ear piece extensions to the end of the nose bar using a sliding mechanism with a scale integrated into it



(measurement D). The final measurement to be taken is the angle which the bar makes with the horizontal ear piece extension (measurement C). This measurement will be taken using a rotating knob which will allow the bar to move at an angle and allow for measurements to be recorded of the specific angle.

If the subject is lying in the face down position the setup will be very similar. The ear pieces will again be inserted into the subject's ears and measurements will be taken the same way as above. The difference will stem from the need to find the location of a distinctive point on the head other than the nose, because the subject will be lying face down. Our client has decided the landmark which they want to locate is called the inion, which is located directly above the spinal cord. The first step for the practitioner is to replace the nose bar with an inion bar attachment. Each bar can be taken out of their sliding mechanism in order to add the new attachment

### Pros

The AIO positioner will allow for very accurate and precise measurements to be taken for the position of the subject's head. The positions of the ears and nose can be determined by using all the measurements on the positioner to create an accurate and reproducible position of the head.

### Cons

A concern regarding the AIO positioner is the comfort level of the subject. With the ear pieces and either adapter (nose bar or inion bar) around them, the subject is not going to be maximally comfortable. The ease of setup is also a major concern of the AIO positioner. Based on the structure of the AIO positioner, the subject must be located inside of the MRI tunnel while the head positioner is attached. This type of setup will be

very hard on the practitioner to perform. The final concern of the AIO positioner is difficulty of construction. Since the positioner will need precise measurements located along structure the manufacturing will require high precision.

## **Alternative #2 Neck Positioner**

### Overview

This design will employ a current commercial neck holder to keep the subject static while the subject is in the MRI tunnel. The neck holder would be purchased commercially and modified to meet our needs.

### Operation

In this design, the subject will put on the neck holder while outside the MRI tunnel. The subject will then lie down and be placed inside of the MRI tunnel. Once the subject reaches the final depth within the tunnel an adapter



Figure 4.  
Example of Head Holder.

will be placed from the neck holder to the TMS holder. The mechanism will extend from the sides of the neck holder back towards the TMS holder. The two pieces will mount by placing a pin through the locking mechanism and the TMS holder. The locking

mechanism will have an adjustable length in order to give reproducible measurements. The mechanism will also be made out of an MRI safe material which must be durable.

### Pros

The major advantage of this design is the ability of the subject to be positioned while outside of the MRI machine. This minimizes the difficulty in setup which stems from the tight space inside of the MRI machine. The subject will have a high comfort level with the neck holder since the majority of neck holders on the market today place a strong emphasis on comfort. The design would allow ease of construction compared to the other two designs because of the relatively simple parts compared to the other positioners.

### Cons

The neck holder design will not allow for extremely accurate and precise measurements as in the other designs. This is a severe deficiency of this design as accuracy and precision are major concerns of our client. The cost of this design will be dependent on the type of neck holder which would be purchased, but the neck holder could cost more than the raw materials needed for the other designs.

## **Alternative #3 Flat Head Plate**

### Overview

The “head plate” positioning device accomplishes the main goal of accurately and precisely positioning a subject’s head in the same location with respect to the TMS device in a two step process.

### Operation

The first step is to secure the subject to a head plate to deny head movement. Next the head plate must be secured to the TMS holder. Once the head is positioned on the head plate and the subject is

put into the correct testing position, a pin can be inserted first through one side strut of the head plate device, then through a hole drilled through the front of the base of the TMS holder, and out again through the other strut of the head plate

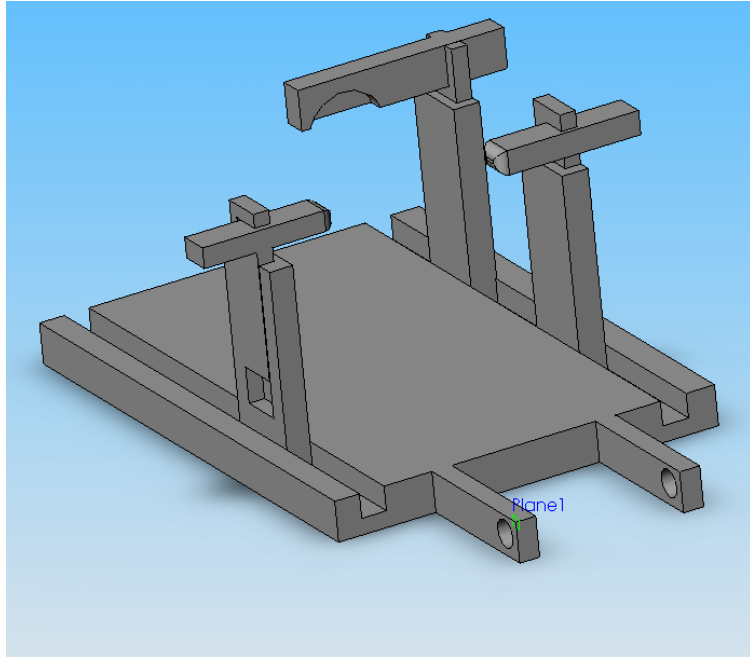


Figure 5.  
Diagram of Head Plate Design.

device. This will ensure the TMS holder and the head plate cannot move relative to one another guaranteeing that the subjects' head will always be in the same location.

Positioning a subjects' head on the head plate in an accurate and precise fashion will be accomplished by having the positioner attach to three distinct points on the head. While in the fMRI a subject must be in two positions; face down and face up. While the subject is on their back the three points will be both ears and the chin, while on their stomach the three points will be the ears and the inion.

When the subject is lying in the face up position, the ear attachments will be slid along the plate with the measurement of the location of the ears relative to the plate being

recorded. Once the ear pieces are in line with the ears, the ear pieces will be extended so the ear pieces enter the subject's ear (as seen in Figure 5) and again a measurement will be taken. The subject will then be able to rest their chin on the adjustable chin rest, with this measurement taken for consistency.

If the subject is lying in the face down position two new attachments will be added to the plate. The first will be addition of a massage pillow at the base of the plate which will allow for breathing and comfort. The second attachment will be replacement of the chin holder with an inion position. The inion positioner will move in the same way as the chin holder, but will touch the tip on the inion instead of the chin.

All movable parts on the head plate device will have measurement scales associated with each, in the form of painted tick marks every millimeter.

### Pros

This design provides an accurate way to measurably reposition the subject's head with respect to the TMS holder. The base plate system allows for greater stability in positioning as well as increased ease in setup due to positioning prior to entrance in the MRI machine. This device allows for multiple attachments which can provide more accurate measurements.

### Cons

A limiting factor involved with this design is the inability of the subject to easily communicate if needed due to chin constraints. The chin position bar, as seen in Figure 5, may limit comfort of the subject. Also, the ideal head plate size may interfere with the size constraints of the birdcage, which would require further modifications.

## Product Evaluation

To determine the best design to construct a design matrix was created. The most important aspects of the design were the accuracy and reproducibility of the final product. These aspects were chosen as the most important because our client's major need was to be able place a subject's head at the exact same location in multiple environments. Next the subject's comfort level was considered. Our client did not stress the importance of comfort, only that the subject be relatively comfortable. The ease of setup was also not a major concern of our client, as much time is already going to be taken to ensure correct measurements. Finally the cost and construction are not major obstacles in the design matrix because all of the products can be constructed and all are within reasonable price range.

After consideration of the pros and cons of the three designs, the head plate was determined to be the best option. The major reason for choosing this design was its ability to give accurate and reproducible measurements.

	All-In-One	Head Plate	Neck
Accuracy (out of 10)	8	9	2
Reproducibility (out of 10)	9	10	2
Comfort (out of 5)	3	4	3
Ease of Setup (out of 5)	1	5	2
Construction (out of 5)	1	1	5
Cost (out of 5)	3	3	5
Total	25	32	19

Table 1.  
Design Matrix.

Also the design allows for the measurements to be taken out of the MRI machine, allowing for a much easier setup compared with the All-In-One design.

### Final Design: Curved Head Plate

#### Head Plate

The head plate was constructed out of the 2" x 12" x 24" grey piece of PVC. This was done using a milling machine to create the curved surfaces. The curved surface is imperative to the design because of the need for a curved base to rest on

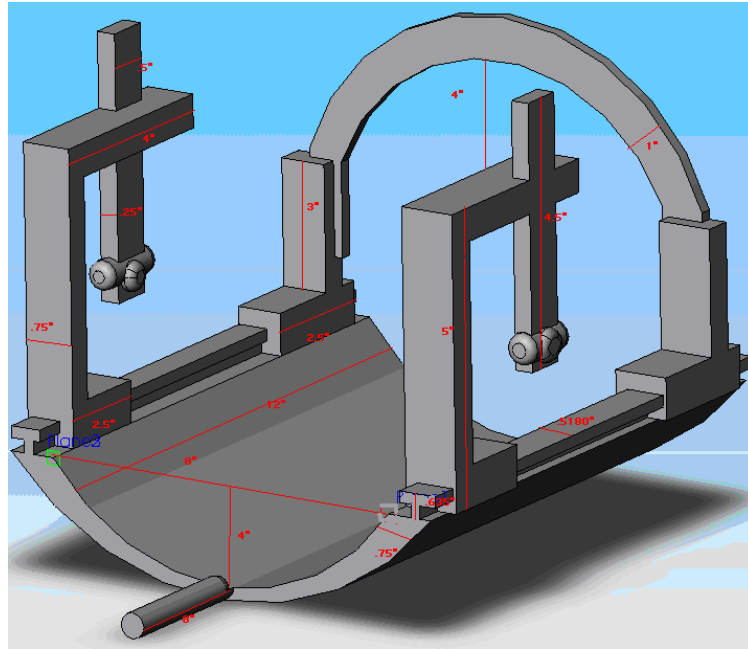


Figure 6.  
Final Design in Solid Works

the bottom of the birdcage and allow enough room for the patient's head. The head plate will also attach to the TMS holder, ensuring relative reproducibility of the system.

#### Rails/Slider

The rail and slider piece were cut out of the 3/8" x 12" x 12" piece of grey PVC. These pieces were also constructed using the milling machine along with a T-shaped cutter. The T-shape was selected for the ease of manufacturing and structural integrity.

#### Ear Pieces

The ear pieces were constructed out of a 3/4" x 12" x 12" piece of Grey PVC using the band saw. The ear piece is design to rotate allowing lateral displacement with respect to the sliding track. The sliding mechanism will be then drop down from above and into the subject's ear allowing for minimal movement.

### Chin Piece

The chin piece was constructed out of a 3/8" x 12" x 12" piece of grey PVC, cut by the band saw. The chin piece will be snugly positioned on the underside of the chin and locked into place. Connected to the chin piece will be an inion attachment. This attachment will have a sliding

bar which will move along the length of the head plate at an angle of 30 degrees. The sliding bar will extend until contact with the inion.



Figure 7.  
Final Product.

### **Conclusion**

In completing this project, the design specifications of our client have been met with our design being inexpensive and easily reproducible while being fully functional for our client. Ethical concerns of this project were limited to the subject's comfort. A certain level of comfort for the subject needed to be maintained for a long time, but at the same time this level was up to our discretion. The comfort level of the subject needed to be balanced with the precision and accuracy of the system. The decision was made to maintain acceptable levels of comfort for the subject while at the same time maximizing precision and accuracy.

### **Future Work**

Upon completion of our final report more construction is needed to complete our prototype for use in TMS tests. Next week, we will be purchasing disposable ear plugs to



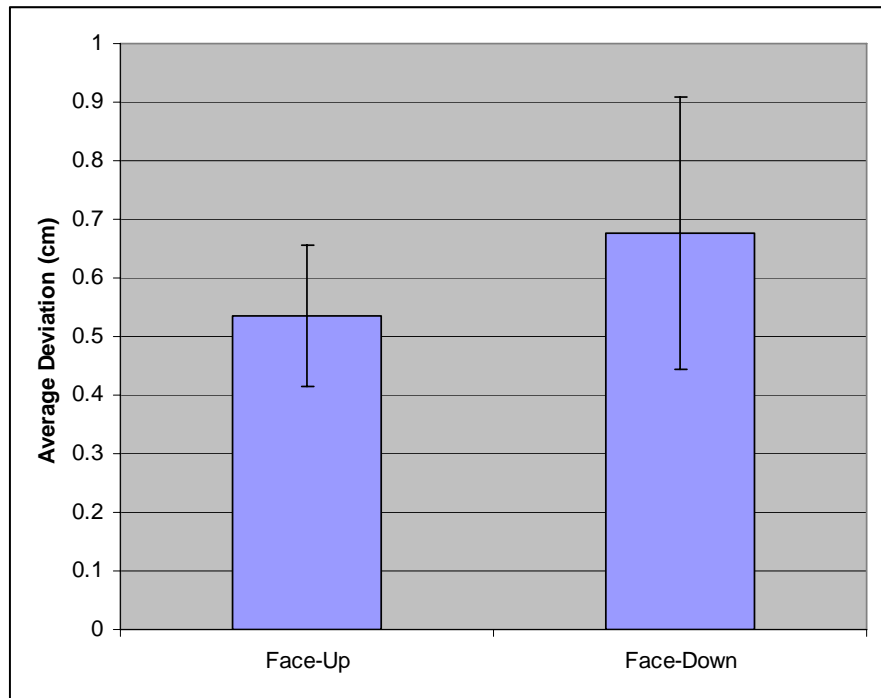
attach to the ear positioning devices which have been depicted in the Solidworks picture of our final design.

Another key component to be added is the measuring system for accurate reproduction of orientation. The sliding tracks will be composed of scaled marking tape available from McMaster-Carr. Radial measurements of the rotational ear piece, which current products haven't been made to fit our device, will be created using Adobe Photoshop.

Once the scaling system and construction of our prototype is complete we will perform an accuracy and precision test on our device. In order to perform these tests we will be using a

molded human skull replicate and marking the skull in a desired position. After proper

orientation, we will remove the skull and displace the positioning aids. The skull and positioning aids will then be placed back in the device and repositioned through use of



Graph 1.

Expected Results: This plot demonstrates expected accuracy and precision results based on ten replicates performed on a human skull replication positioned in the head plate prototype. The expected SE bars will be calculated non-conservatively.

the scaling tape. Once in place we will measure the distance the positioning aids are from the original markings and this technique will be repeated ten times in both the face-down and face-up positions. An average of deviations from the original marking and non-conservative standard error bars will indicate the accuracy and precision of our prototype. This can be viewed in Graph 1.

Final positioning will occur once the head plate positioner is located in the MRI scanner and attached to the TMS holding device. In order to attach to the TMS holder a threaded rod will be added to the head plate positioning system and bolted into a threaded slot in the TMS holder. Addition of the threaded rod cannot take place until our client and his assistant chose to add a threaded slot to the TMS holder.

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# PDS

## **Problem Statement:**

Our client desires an efficient technique or device for repositioning a patient's head with respect to the TMS holder after moving from an EEG test to an MRI scan. This method must precisely relocate a patient's head within the limited space available and be transferable from one patient to another. Improvements for various factors for convenience are necessary and include, but are not limited to: reusability, ease of set up, precision and accuracy. The apparatus used will be transferred to numerous patients so an efficient sterilizing method must be implemented.

## **1. Physical Requirements:**

- a. *Performance*: The technique or instrument used to relocate the patient's head should precisely and accurately position the patient in a manner identical to previous tests with respect to the TMS holder. Operational conditions require this method to restrict patient movement the duration of tests in a comfortable yet efficient manner.
- b. *Safety*: Devices used in psychological tests shouldn't inflict pain or cause harm to the patient. The method used to restrain the patient in position must rest comfortably on the patient and have ease of quick removal in case of need to end the test abruptly due to a patient undergoing claustrophobic affects due to extended periods in the MRI scanner.
- c. *Accuracy and Reliability*: The ability to relocate patients in the exact location with respect to the TMS holder is of utmost importance because of the need to effectively stimulate specific regions of the brain, which may only have at most

- 1cm of error. In order to achieve precise data from these tests, the technique used to position the head must be able to accurately situate the patient in the different stages of testing.
- d. *Life in Service*: The relocating device will have a long time in operation. The tool used to relocate patients will be used for all patients undergoing psychological testing and is needed multiple times for each patient.
  - e. *Operating Environment*: The apparatus used will be placed in multiple environments ranging from EEG testing sites to MRI scanners and must be able to withstand being transferred to and from different testing sites.
  - f. *Ergonomics*: An essential feature is comfort of the patient while restrained by the device. Patients will be tested in the MRI scanner for extended periods of time which makes stress-free positioning a necessity. Also the relocating device will have to function while the patient is either in the prone or supine positions.
  - g. *Size*: A small size is required due to the limited space within the MRI scanner. Within the scanner the “birdcage” surrounds the patient’s head which has a total diameter of 28 cm which will need to be enough room for the patient’s head, head rest, TMS device and the relocating device.
  - h. *Weight*: Lighter weight is favorable in order to reduce strain on the mounting plate which is held in place by a nylon screw.
  - i. *Materials*: Supplies used in the device are limited to anything non-metal or non ferromagnetic metals in order to prevent interference with the MRI scan. Materials must also be durable for repeated use yet sterility is necessary due to use on several patients.

- j. *Aesthetics, Appearance, and Finish*: Not of importance, difference in color in each piece of the device could facilitate ease of use.

## **2. Operational Requirements:**

- a. *Quantity*: Only one will be produced due to the specific nature of these psychological tests.
- b. *Target Product Cost*: The tests and scans are very expensive and highly funded but cost on this piece of equipment should be minimized.

## **3. Miscellaneous**

- a. *Standards and Specifications*: Convenience for those running tests, ease of use and quick setup should be emphasized.
- b. *Customer*: Dr. Brad Postle
- c. *Patient-related Concerns*: Minimize stress and maximize comfort