

## **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 cell membrane holds a potential difference that can be deviated by an externally applied electric field, depolarizing the membrane and activating excitable tissue. 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.

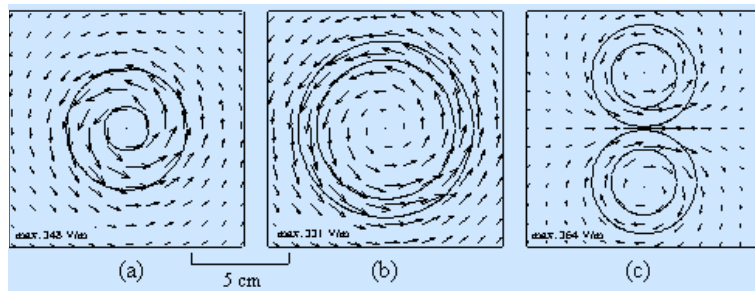


Figure 1. TMS Magnetic Field Diagram (Ruuhonen)

### 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 images of the body. It 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 experimentation has extensively researched memory formation. Though the use of TMS is relatively new (the past decade or so) it is being used by researchers. The 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 the 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 acquisition. 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.

Two different testing locations must be used in the client’s suggested experiment, each location with its own specific testing apparatus. A portion of the experiment requires the TMS unit be inside of the fMRI tube with the subject. Another portion, one that may occur up to two weeks later, 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 the client has contacted us about designing a head positioner to make sure the head is always in the same location at each testing environment.

The client has provided us with a TMS holder (as seen in Figure 2), which is used to hold and

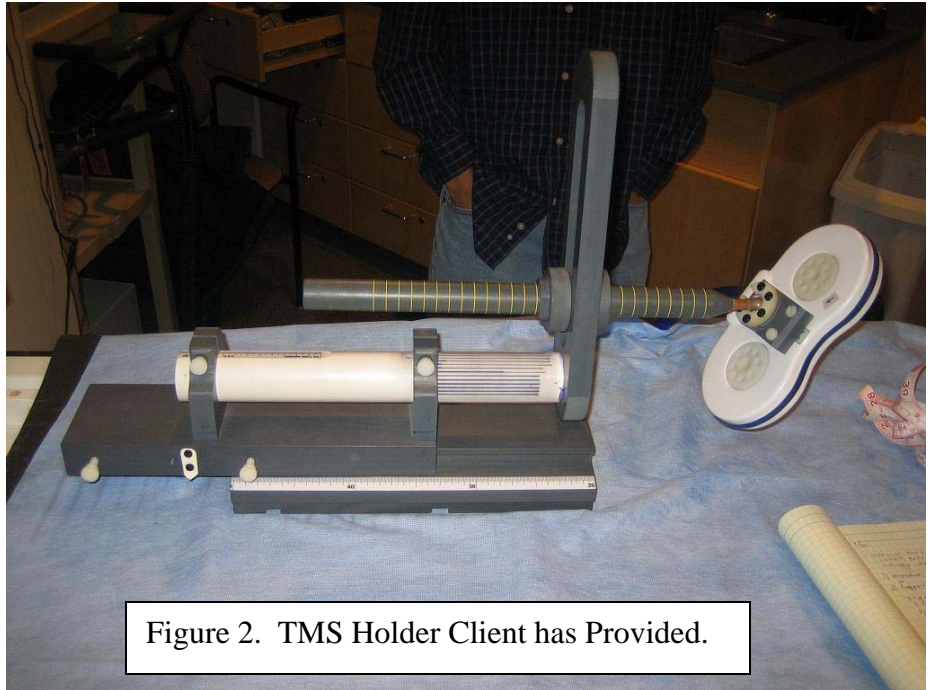


Figure 2. TMS Holder Client has Provided.

position the TMS coil. Since the TMS holder will be in a standard position in all locations the TMS holder 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 being sensitive to a number of functional restrictions. These restrictions are due to multiple experimental locations, multiple subjects, 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 in 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 of 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 the client's experiment. There are three specific brain regions located around the head. The head positioning system must be able 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.

## Design #1 All-In-One Positioner

### Overview

The All-In-One design utilizes the position of the TMS holder to achieve maximum levels of precision and accuracy.

The All-In-One design allows precise positioning of the subjects head in the EEG and MRI machine while at the same time allowing the subject a small amount of

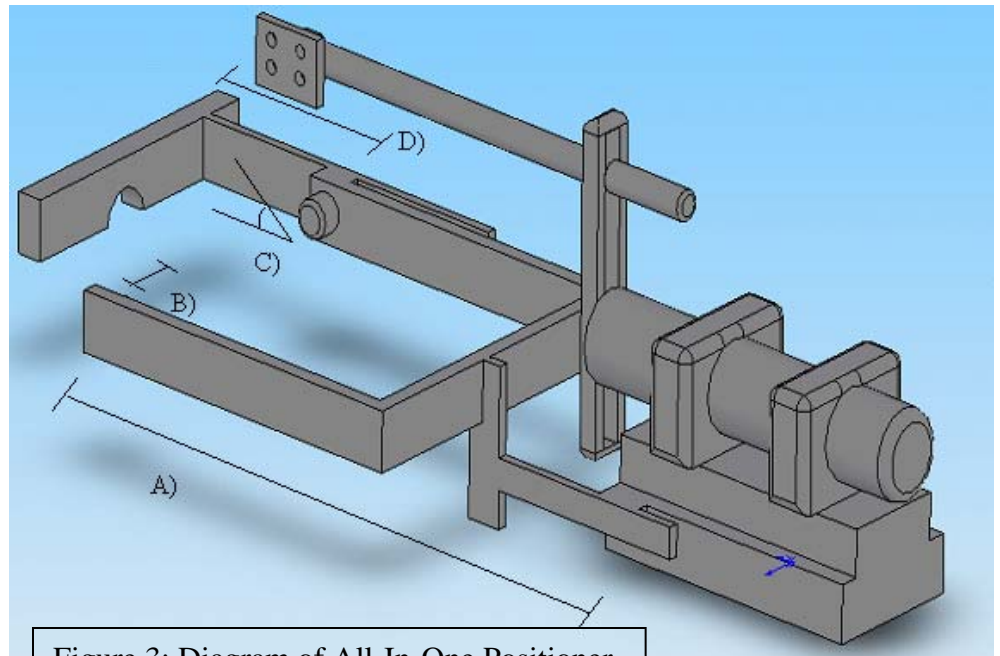


Figure 3: Diagram of All-In-One Positioner

comfort. The positioner will be made out of an MRI 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 their 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 measurements 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 measuring devices built in to determine the position of the nose relative to the holder. The first is the ability to determine the distance from the ear piece extensions to the end of the nose bar, this will be done using a sliding mechanism with measurements 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. The 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 of 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 the difficulty in the construction. Since the positioner will need precise measurements located along structure the manufacturing with this high level of precision will be very difficult.

## Design #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 from a commercial retailer and modified to fit the needs of our current system.

### 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 will be placed from the neck holder to the TMS holder. The mechanism will extend from



Figure 4: Example of Head Holder

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 very minimal size constraints 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 emphasize on comfort. The design would allow ease of construction compared to the other two designs because of the relativity 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 severely detrimental to this design as this is a major concern of the client. The cost of this design will be dependent on the type of neck holder which would be purchased, but according to previous findings the neck holder could cost more than the raw materials needed for the other designs.

## **Design #3 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

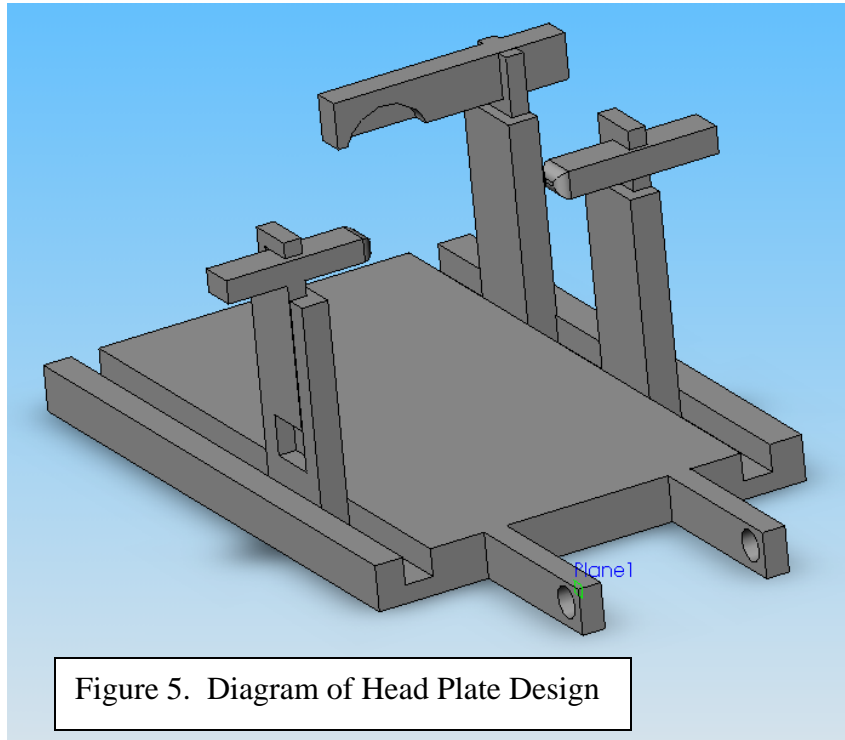


Figure 5. Diagram of Head Plate Design

device. This will ensure the TMS holder and the head plate cannot move separately from one another guaranteeing that the subjects' head to 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 region. 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 again 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 of which is the addition of a massage pillow to the base of the plate which will allow for breathability and comfort. The second attachment will be the replacing 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 a measurement scale 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.

## **Future Problems**

The limiting constraint of TMS positioning are the restrictions within the MRI scanner. The limited space inside the MRI “birdcage” could make adjustments difficult. In order to position numerous subjects of different sizes the device must be fully adjustable to accommodate the difference in facial dimensions as well as position them while lying face down. Although the TMS positioner serves a relatively simple purpose there are a variety of potential problems due to materials. In order to create a device feasible for MRI use, non-magnetic or non-ferromagnetic materials must be used in construction. Non-magnetic materials limit our design, durability, and/or strength. Plastics are a common material used in MRI scans but are a possible source of error caused by bending of the plastic and eventual shattering of the device. Another potential problem could be locking the positioner into the TMS holder while inside of the MRI scanner. The subject must be loaded with the positioner in precisely the right position so that when the subject slide into the scanner the positioner will mount easily into the TMS holder.

The most concerning potential problem is a result of any combination of the previously stated problems causing imprecision and inaccuracy of head positioning within 1 cm which would undermine the entire design. In order to reduce this risk, multiple tests for accuracy, precision, and durability will be conducted.

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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