Patient Positioning Device for Magnetoencephalography

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Abstract

Sumitomo Heavy Industries (SHI) has developed a unique magnetoencephalography (MEG), a device to take measurements of magnetic signals in the brain, which does not require a magnetically shielded room to operate. This paper describes the design of a device which positions a patient in SHI's MEG with minimal patient effort, as compared to the current standard. The design utilizes an adjustable chair guided by a track and actuated by a hoist. This device will be utilized by SHI during trials of the MEG prototype and inspire future thinking on patient access to the MEG.

Keywords: Magnetoencephalography, MEG, Ergonomics, Brain Imaging, Hardware, Chair

1. Introduction

A magnetoencephalography (MEG) scan quantifies the brain's electrical activity by measuring the naturally occurring magnetic signals that it produces. The MEG uses superconducting quantum interference devices (SQUIDs) that can measure magnetic fields on the order of 10 to 100 fT (1×10^{-15} T). MEG studies are completely non-invasive[1] and more spatially resolved than electroencephalogram (EEG)[2] for measuring neural activity. An MEG can also capture up to 10,000 images per second, making it thousands of times faster than MRI.[1] Currently, the major clinical application of MEG studies is the surgical treatment of epilepsy.[1] Research points towards MEG studies ultimately being applied to researching and diagnosing a variety of neurological diseases such as autism spectrum disorder (ASD)[3] and Alzheimer's disease.[4]

In any laboratory or clinical environment, there are many sources of magnetic noise that are several orders of magnitude greater than the brain signals measured by an MEG.[4] Sources ranging from electronics and elevators to MRI machines to naturally occurring geomagnetic fluctuations can cause disturbances in the MEG output.[1] Therefore, in order to eliminate as much noise as possible, magnetically shielded rooms are used to conduct MEG tests.[4] These rooms, however, are extremely costly and require a great deal of renovation to existing architecture in order to be installed, resulting in the inaccessibility of these tests at most research and clinical facilities.[4]

In order to circumvent the need for specialized infrastructure, Sumitomo Heavy Industries, Ltd. (SHI) has developed an MEG system that employs superconducting magnetic self-shielding, which does not require an expensive magnetically shielded room.[5] The challenge of such a system, however, is that superconducting magnetic shield (SMS) covers the subject, as can be seen in figure 1, causing difficulty for a subject getting into and out of the machine. The goal of this project is, therefore, to design and build a patient positioning system that satisfies the material, patient size, and positioning requirements of SHI's MEG system.

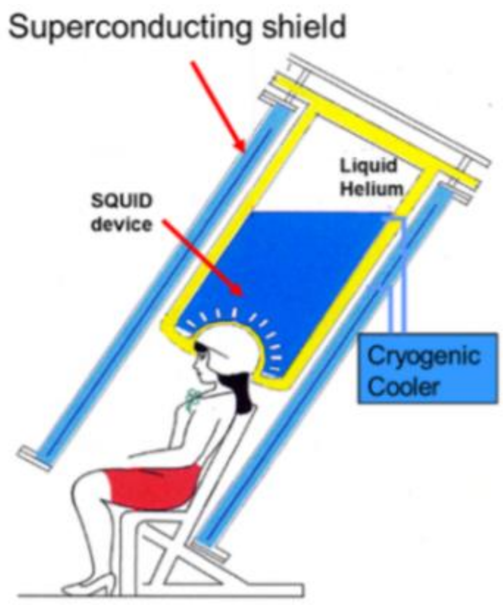

Figure 1. A schematic of the SHI MEG system. [4]

Due to the system's extreme sensitivity to magnetic noise, no metals can be used in any possible solution within 10 cm from the bottom of the MEG. Furthermore, due to the MEG's sensitivity to vibrations and movement, the MEG must not be moved, tilted, or acted upon by any outside force in any manner. Any motion of the system will require resettling of the SQUIDs and will necessitate recalibration[5], which is a time-consuming process. Thus, nothing can be affixed to the MEG. Early patient insert/egress concepts were developed from similar devices such as mechanics chairs[6] and creepers[7] and dentistry chairs[8], which employ multiple degrees of freedom and actuators in order to move a subject from a lying down position into a reclined seated position. These systems can be used as a model of how to initialize the subjects in a comfortable position that will fit into the MEG and then move them into a seated position within the MEG, all in a controlled manner.

The device will have immediate research applications as part of SHI's MEG system. Researchers will use the MEG that will incorporate the proposed system to research a variety of topics ranging from cognitive disorders to language processing and brain machine interfaces.

2. Background

Currently, a patient must squat and shuffle backwards into the MEG, ultimately sitting on a narrow wooden chair. This is a difficult and awkward maneuver. Due to the novelty of SHI's MEG machine, the specific design of an adjustable chair on tracks proposed here is unique. Inspiration was drawn from several existing devices. In medical settings, precise positioning is required in applications such as radiation therapy. In one application, a patient in a chair is manipulated via a multi-jointed robotic arm.[9] This system is most relevant when space is not a constraint, owing to large robotics components.

Actuated chairs are further demonstrated in dentistry settings. The mechanism used in most dentist chairs allows for raising and lowering of a reclined patient, along with adjustment of the recline angle of the patient.[8] Generally these systems are heavily electrically actuated, which is not possible for this application due to the electrical signals' and metal components' interference with the MEG readings. The coupled reclining and raising degrees of freedom, however, can provide further insight into which degrees of freedom we should restrict while inserting the patient into the MEG. Contrary to the dentist chair, another medical application of a chair with many controllable degrees of freedom is the Maquet Betaclassic Mobile Operating Table. This chair allows for independent control of each of the patient's limbs and is controlled completely pneumatically.[10] Pneumatic actuation is promising for the purposes of the MEG mechanism, as it would not induce any interferences with the MEG signals.

Several products of interest are not standard medical devices but nevertheless provide key insights. A bath lift, for instance, assists low-mobility persons in and out of a bathtub and features independent control of the height and back adjustment. This design satisfies the need to both raise the subject into the MEG tube and adjust the hip/back angle to account for different body sizes. Completely free and independent control of both degrees of freedom, however, introduces an unnecessary level of complexity and possible points of conflict between the patient and the MEG. It is preferred that the subject's motion is as controlled as possible to prevent any physical interference.

Products like the Human Hoist[6], intended for ergonomic workplace usage, include wheels, a feature that would allow for a subject to move away from the MEG machine for easier positioning before and after the scan. Human Hoist also couples hip/back angle, a feature which is incompatible with the small space of the inside of the MEG machine.

Furthermore, products such as the hybrid mechanic's chair and creeper design provide exceptional range of motion for the user[7]. Although this type of mechanism would provide enough adjustability to comfortably enter the MEG, it would require the patient to be comfortable with the controls of the chair, which can be complicated at first. Additionally, allowing the patient more degrees of freedom than is necessary, as with the bath lift, can complicate and possibly hinder the process of entering the MEG and impact the safety of the patient themselves.

3. Design

3.1 System Overview

The patient positioning system consists of an adjustable patient chair that can roll and articulate along a predetermined track into the MEG. The insertion process is shown below in figure 2.

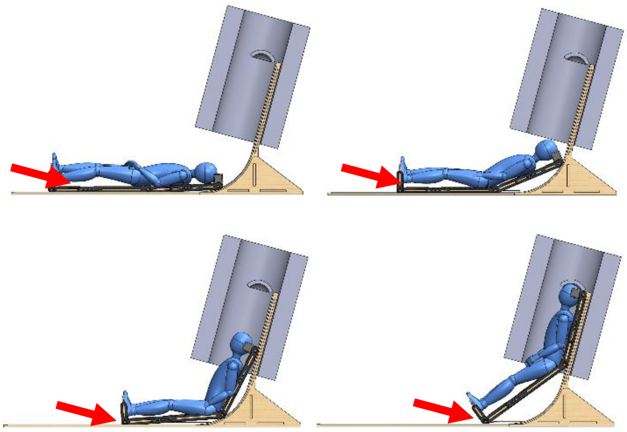

Figure 2. Patient insertion process.

The use of the track allows the application of force along a single direction from the feet of the patient (shown in red in figure 2), avoiding the mechanical complexity associated with an independently actuated multiple degree-of-freedom chair design.

3.2 Chair Assembly

The chair assembly consists of two adjustable sections with a hinge point at the patient's hips (figure 3). The adjustable sections compensate for differences in patient torso and leg length[11]. The sections are comprised of Delrin plastic frames tied together with plywood platforms by Nylon screws. The frames have an interlocking sliding design which provides structural rigidity throughout the adjustment range.

The rolling contact points of chair are at the feet, hip, and head locations. They are comprised of Delrin plastic rollers with Nylon bearings on Delrin shafts. The rollers have flanges to constrain side-to-side motion of the chair, such that it does not leave the track. Plastic shields protect the patient from the rolling elements.

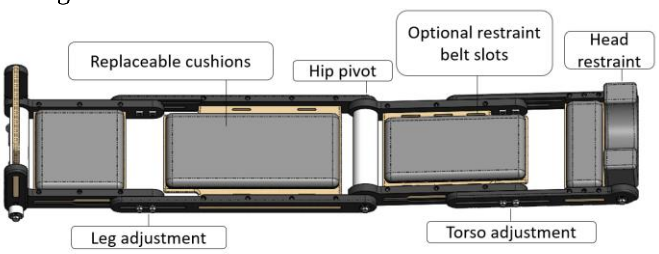

Figure 3. Chair assembly overview.

3.3 Track Assembly

The track assembly consists of two subassemblies: the flat floor section and the curved section that extends into the MEG (figure 4). The flat section guides the chair to lie flat outside the MEG, allowing for patients to get on and off the chair. The curved section, made with interlocking plywood pieces glued and pinned together with dowels, guides the chair into the MEG. The areas contacted by the rollers are covered with UHMW plastic to reduce friction and improve durability. The two sections are connected with metal brackets, which are out of the interference zone of the MEG. The track assembly includes mounting points for the hoist used to drive the patient chair.

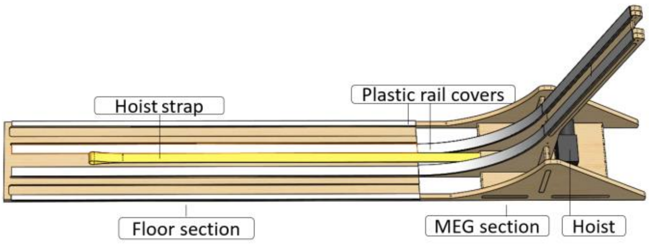

Figure 4. Track assembly overview.

3.4 Power System

A hoist, located in the rear of the track, drives the system by pulling the chair into the MEG. The hoist pulls the chair from the shaft at the feet, as shown in figure 5, taking advantage of the solely horizontal path of the foot of the chair. Although a winch, rather than a hoist, is generally used for horizontal pulling applications, a hoist was used to actuate the chair due to its mechanical locking brake, which allows it to reliably hold a suspended load for an extended period. This is especially important for this application, as a patient will need to be held in the MEG for the entire duration of a single study.

Figure 5. Yellow hoist strap attached to foot panel shaft.

The force profile of the tension in the hoist strap as a function of the angle of the patient's back as they are pulled into the machine (starting at zero degrees and ending fifteen degrees from vertical) is shown in figure 6. From this profile, the maximum load the hoist must pull was determined and thus informed its required specifications.

Figure 6. Force profile on the hoist as a patient is lifted into the MEG.

A hoist rated for 1100 pounds was chosen in order to maintain a large safety factor of over 10, as this system will be holding patients in a clinical setting. Furthermore, a speed of 12 feet per minute was determined via experimental testing to be a comfortable speed for insertion and egress, while allowing for a comfortable 30-second standard for patient egress time, as per the functional requirements. The hoist chosen is controlled by the patient via a remote, allowing for micro-adjustment of their position while inside the machine and access to an emergency stop should the need arise. Furthermore, the hoist has a clutch that can be disengaged in order to release the line instantly for emergency egress.

3.5 Ergonomics

In order to best support patients in the chair, several comfort measures were implemented. For the patient's head and neck, there is a concave, semi-circular pillow (see figure 7). This cushion is removable and can be repositioned to best suit the needs of the patient.

Figure 7. The head/neck support cushions.

Additionally, four cushions (see figure 8) improve patient comfort. Constructed of ⅛-inch plywood backing and 2-inch foam covered by synthetic fabric, the cushions are made to be easily wiped down between patients. These cushions are attached to the head, back, thigh, and shin panels by 3M Dual-lock strips. They are removable for easy cleaning and customization for each patient.

Figure 8. The cushions attached to the chair.

The plywood foot panel offers a place for patients to rest their feet during a scan. Plastic, semi-circular guards prevent patients contact with rolling elements. Finally, optional buckling straps can be added for improved patient retention. The straps are adjustable in length to accommodate different patients. Five slot pairs along the back and thigh panels allow for flexibility in number and location of straps.

4. Testing and Results

After completing the first prototype of the chair, extensive testing was conducted to determine if all the functional requirements where met. This consisted of three stages of testing.

The first stage of testing was a simple design inspection. This involved inspecting all materials of the assembly to ensure that non-metallic components where used within the restricted zone

The initial inspection was followed by static position testing. The goal was to confirm that the device would be able to fit within the MEG, meet patient size compatibility, and be comfortable enough to support a patient for 30 minutes, the duration of a typical MEG scan. This included testing the device with several people, ranging from 1.6 to 1.9 meters in height. All these patients fit without reaching the limits of the chair. To ensure that the chair was comfortable, patients tested the chair for the full 30-minute duration and reported no significant discomfort.

The third phase of testing was the dynamic portion. This testing had two main objectives. The first objective was repeatability. This was assessed by performing 50 insertion and extraction cycles. The device was able to do 50 continuous insertions with no discernible variance in its placement within the machine. The second objective was ensuring patient size compatibility during movement. This was done by inspecting the leg and chest clearance for a typical-sized patient as a function of distance before full insertion, plotted in figure 9. These measurements are shown in figure 10. By inspecting these results against body measurements of prospective patients, the operators of the MEG can determine whether the patient will be likely to fit within the machine.

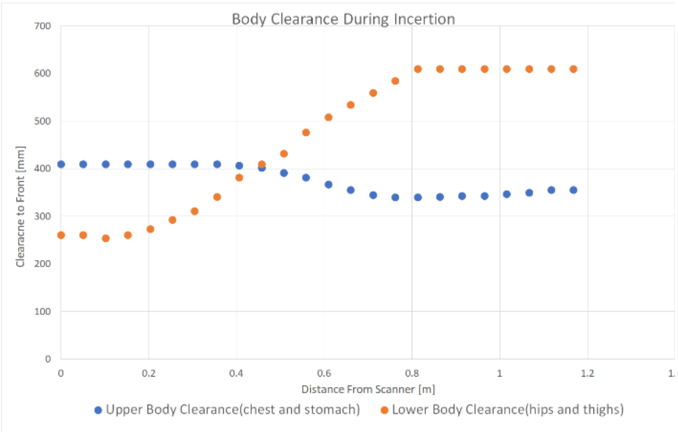

Figure 9. Body clearance.

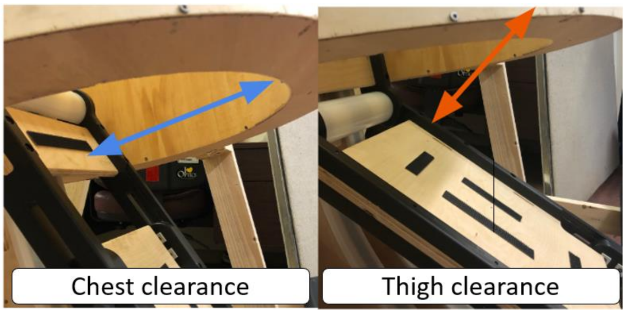

Figure 10. Chest and thigh clearance measurement locations.

5. Discussion and Future Work

The SHI MEG machine is unique because it does not require a fully magnetically shielded room. This comes, however, with some limitations. The track and chair system described in this paper allows for more comfortable entry into the machine for most adults but does not accommodate individuals who do not fit within the size constraints. Specifically, children, shorter adults and people of larger girth will not fit. Additionally, since the track and chair system requires the patient to begin lying down on the floor, some patients may find it difficult or impossible to position themselves on the chair to undergo a scan.

For improved comfort, it may be worthwhile to explore alternate cushion designs and foot placement. In the current design, a patient's weight is supported mostly by their feet on the footrest. Alternatively, a convex seat cushion could be used in conjunction with a collapsible footrest, such that the patient is supported mostly by their buttocks (figure 11).

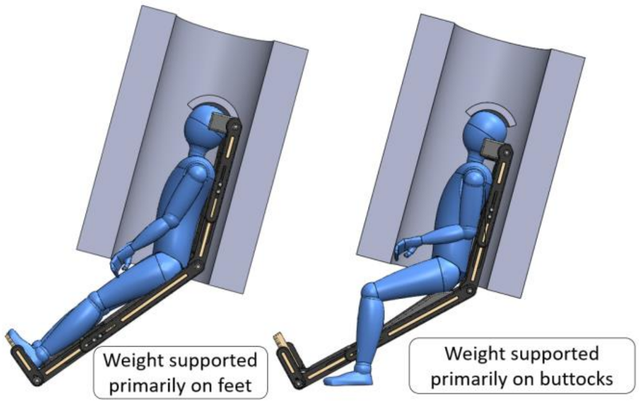

Figure 11. Alternative cushioning concept

In order to accommodate a wider range of people the following changes to the next version of the MEG may be necessary.

5.1 Higher Elevation (figure 12)

If the entry aperture for the machine was higher off the floor, the angle at which a patient would need to bend in order to enter the machine would be less severe. This would require a minor redesign of the track and chair. This would also open the possibilities of starting in a seated position or starting further from the floor.

5.2 Larger Diameter (figure 13)

With a larger entry aperture, the MEG machine would be able to accommodate larger patients. Currently the track and chair system have constriction points at the chest and thighs, and a larger diameter opening would increase clearance. Also, the radius of curve on the track could be made larger, increasing comfort.

5.3 Flared Opening

The conflict points between the patient on the chair and the MEG are mostly at the bottom front edge of the entry point. Expanding the diameter of the tube entry point with a flared opening would greatly increase the range of sizes accommodated by the system.

5.4 Door Opening (figure 14)

If the front of the MEG could be hinged to open to insert a patient, it would be possible to make a much simpler system for holding and positioning the patient. This could even open the possibilities to pre-position the patient for scanning before the scan begins.

5.5 Shorter Tube

The best case scenario for the ergonomics of this system would be if the magnetically shielded tube could be shortened, thus decreasing the necessary travel inside the machine. This would improve physical comfort, reduce stress and increase the range of patient sizes accommodated. As with adding a door, this may not be feasible given the sensitivity of the MEG technology.

Figure 12. Higher elevation.

Figure 13. Larger diameter.

Figure 14. Door opening.

6. Conclusion

The device presented here effectively inserts patients into a model of SHI's MEG. It is designed to fit within the MEG's volume constraints, and, without metal materials, it will not interfere with the function of the MEG. Patients will be able to enter the MEG with minimal effort and will be comfortable for the duration of the scan. The device is now ready to be fully incorporated with the full MEG prototype.

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