Adjustable Lightweight Transcranial Magnetic Stimulation Helmet for Brain Injury Rehabilitation

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Abstract— **This project aims to design a lightweight helmet that utilizes the fundamentals of transcranial magnetic stimulation (TMS) to aid in the treatment of brain injuries such as stroke. The proposed design consists of a PVC framework that can hold six detachable units, two of which are motor-units for housing and rotating disc magnets. Each 3D-printed motor-unit holds two neodymium magnets, which can be rotated at two different speeds via a switch, and arranged along the framework of the helmet to target specific areas of the brain. The objective of this project is to produce a prototype helmet to support clinical studies on the efficacy of low-frequency low-intensity TMS therapy for a prolonged period of time.**

Keywords—transcranial magnetic stimulation; brain injury; rehabilitation; neodymium magnet; rotational magnet field

I. Introduction

Transcranial magnetic stimulation (TMS) is a non-invasive method of brain injury rehabilitation that uses a magnetic field to stimulate targeted areas of the brain. The treatment uses coils to create a rapidly changing magnetic field which generates weak electric currents. This causes either a hyperpolarization or depolarization of a cell's membrane potential, inducing controllable manipulations in certain behavior. Originally used for diagnostic purposes, the last few decades have seen a number of studies test the effects of TMS as a therapy option not only for psychiatric and neurological disorders [1], including depression and schizophrenia [2], but for brain injuries – specifically those attributed to strokes, such as inhibited motor control after acute cerebral infarction [3].

Current TMS therapy is performed almost exclusively in a clinical setting. A single round of treatment can take between 20 and 40 minutes, and cost about US$2,500. As the medical conditions TMS is associated with typically require frequent treatments over extended periods of time, the conventional TMS as a rehabilitation option is both costly and inconvenient. This project aims to provide an affordable, convenient, alternative to the standard TMS, in order to expand the accessibility of a promising treatment method. The proposed lightweight helmet will employ rotating permanent magnets on an adjustable framework, so that the induced magnetic field can be moved to stimulate different areas of the brain. Using a helmet, that supplies comparatively weaker stimulus, will allow patients the option of receiving treatment from home and for prolonged periods of time. While the efficacy of this approach still requires further clinical studies, the goal of the present project is to develop a safe and comfort prototype that will facilitate future clinical studies.

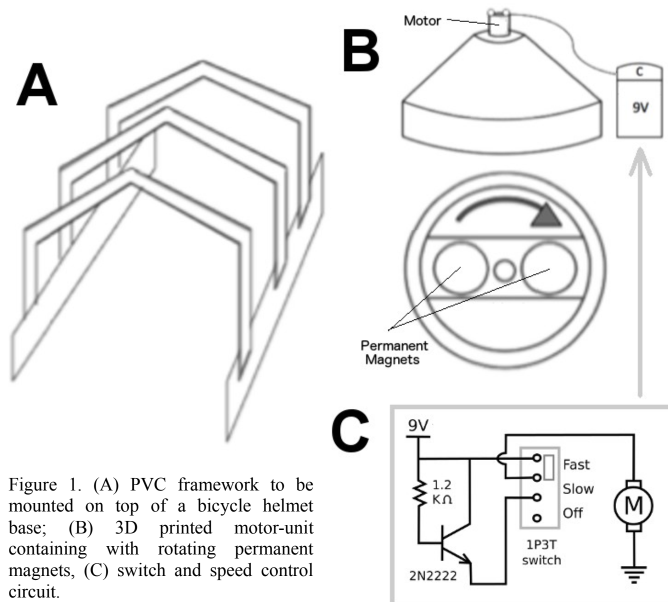

Figure 1. (A) PVC framework to be mounted on top of a bicycle helmet base; (B) 3D printed motor-unit containing with rotating permanent magnets, (C) switch and speed control circuit.

II. Methods

The design of the TMS helmet is based on a previous project [4]. As shown in Fig. 1, the main components of this device include a framework mounted on top of a bicycle helmet base (A), two motor-units containing rotating disc magnets (B), and a switch and speed control circuit for each of the motor-units (C). These components are described as follows.

A. Framework

The framework facilitates the mounting of the motor-units and provides the flexibility of aiming the magnetic fields to specific impaired areas of the brain. The materials of the framework are from PVC pipes, cut and thermally formed to the desirable shapes. The framework contains two PVC strips that are glued to the styrofoam base of a bicycle helmet. Reclosable fasteners (3M Dual Lock® SJ3560) are used to attach three ridges across the top of the head as shown in Fig. 1A. The positions of the ridges are easily adjustable. The bottom of each ridge also has reclosable fasteners for attaching the motor-units and the support units. The support-unit has the same shape of the motor-unit, but does not contain the motor and the magnets; it is used to allow the helmet resting comfortably on the head.

B. Motor-Unit

As shown in Fig. 1B, the motor-unit consists of a small DC motor and two permanent magnets encased in a housing. The housing is designed by using a computer-aided design software (SolidWorks, Waltham, MA) and 3D-printed with ABS plastic. The motor is a generic 12V 300 rpm DC motor that has a 3 mm shaft and a speed reducer gearbox. This motor provides sufficient torque to turn the magnet assembly with the power from a 9V lithium-ion rechargeable batter (600 mAh). Each of the two disc magnets is 1/4-inch thick and 1 inch in diameter, made of N52 neodymium and having a magnetic strength of 0.33 Tesla on the surface. The support-unit is just the housing of the motor-unit and does not contain the motor and the magnets.

C. Speed Control

As shown in Fig. 1C, a simple transistor circuit is used to control the rotational speed of the magnet assemble. A single-pole triple-throw (1P3T) switch is used to select among *Off, Slow, and Fast*. The fast speed is achieved by connecting the 9V supply directly to the motor, resulting in a rotational speed of 68 rpm. The slow speed is achieved by driving the motor via an NPN transistor (2N2222). A 1200-ohm base resistor is used in order to result in a rotational speed of 34 rpm.

III. Results

The final assembly is shown in Fig. 2, which contains two motor-units and four support-units. The support-units provide stability and uniform balance so that the motor-units remain positioned correctly once the location is chosen. All units are connected to the frame by reclosable fasteners, allowing for easy rearrangement, should the area of the brain targeted for treatment change. The framework, in cooperation with the size and mobility of the motor-units, allows the helmet to target the major areas of the brain, within the cerebrum, typically injured when a stroke occurs.

Because a motor-unit operates under its own switch mechanism, each of the two motor-units implemented on a helmet at a time can operate at its own speed (either 34 rpm or 68 rpm respectively). With independently operating motors, different parts of the brain can receive different stimuli at the same time.

An important aspect in the usability of the helmet is the noise caused by the rotation of the magnets. In several tests performed in closed quiet rooms, we determined that the motors increase the decibel reading between 9 and 11 decibels on the "slow" speed. Going from the "slow" to "fast" speed results in an average increase of 10 to 12 decibels. For patients who are wearing this helmet for hours at a time, the noise at the present level may be difficult to bear.

Another issue regarding this prototype is the structural strength. Due to the strong magnetic fields, a motor-unit could be pulled out of the position by a ferromagnetic object nearby. Finally, the maximum rotational speed of the magnet assembly (68 rpm) may need to be further increased in order to enhance the intended therapeutic effects.

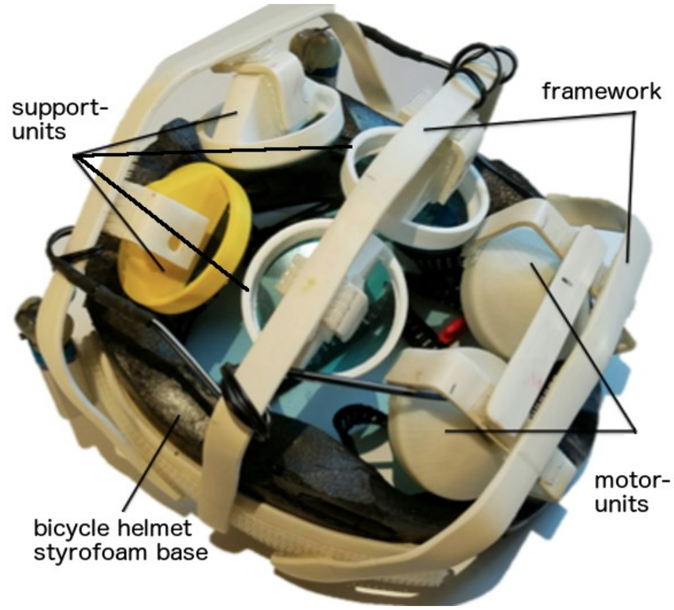

Figure 2. Functional prototype implementing two motor-units and four support-units onto PVC framework. The underside of each PVC ridge contains reclosable fasteners in order to allow all units to be rearranged as necessary.

IV. Discussion

This project has resulted in a functional prototype of the wearable TMS helmet using rotational permanent magnets. The prototype is safe and comfortable to wear on the head. However, it will need further improvements before it can be used in the clinical trial for testing the efficacy. The three issues that have been identified are noise, rotational speed, and structural strength. The motor-unit needs to be redesigned. The motor itself and the speed reduced gearbox generate too much noise. A possible choice is a servo motor cable of continuous rotation via pulse-width modulation controls. The servo motor should also be able to achieve a rotational speed of 180 rpm, about 3 times faster than what the present prototype delivers. The structure strength can be improved by increasing the contact areas of the joints. The penetration depth of the N52 magnets in use is about 10 cm based on a paper phantom. Future work will also include a penetration depth study using a more realistic phantom of the human skull.

References

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