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Mapping the Imagined Speech Location on the Brain Scalp Through Magnetoencephalography (MEG)

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Abstract:** **People with autism speech disorders, paralysis, or muteness cannot communicate via speech. These individuals can think but cannot express and create overt speech. As a result, the system must obtain and interpret the electric and magnetic signal developed at the Scalp during imagined or intended speech. These magnetic signals are termed MEG (Magnetoencephalography), and electrical signals are named EEG (Electroencephalography). This technology must be wearable, non-invasive, and easy to use daily. To make the system wearable, the location of the electrode is essential. Since the EEG has good temporal resolution but poor spatial resolution, mapping the area on the Scalp of imagined speech is difficult. Similarly, the MEG has an excellent spatial resolution. But the MEG signal is weak, only up to 10^{-9} T to detect. Therefore, the delicate magnetic field in the brain due to imagined speech can be seen only by an OPM (Optically Pumped Magnetometer) or SQUID sensor. This paper explores a slightly different type of sensor based on an optically pumped magnetometer with a low cost as the cost of SQUID and OPM is large. A self-made magnetic sensor is used to map the location on the Scalp. The MEG and EEG measurement has been done in terms of PSD (Power Spectral Density). An analysis calculates the deviation compared with a different located point on the Scalp. The area on the Scalp of imagined speech was selected with the help of a literature review. The EEG measurement has done to confirm the location.

***Keywords:** EEG, Imagined Speech MEG, OPM*

I. INTRODUCTION

The human brain's structure and function are very complicated. The most sophisticated cognitive function in the human brain is speech creation. This process begins in the brain with numerous sensory organ functions and ends in the oral cavity via the respiratory tract. There are two reasons to study the brain's ability to comprehend speech. The 1st reason is that numerous individuals could not talk due to different brain illnesses, such as paralysis, lock-in syndrome, autistic speech disorder, or silent persons. They can think but cannot communicate or generate overt words. As a 2nd reason, several BCI (Brain-Computer Interface) systems [1], such as wheelchairs for people with disabilities or patient assistance robots, use speech signals to run automation systems. The acquisition of electrical signals produced during distinct brain activities may be used to comprehend speech creation in the brain. Various Invasive and non-invasive methods are available for receiving electrical activity. The ECoG (Electrocorticography) is one of the non-invasive techniques. The electrodes are surgically implanted in the brain's cortex in the ECoG. This technique is most accurate and precise. However, this procedure is not suggested for practical usage since it requires surgery. The other method is the EEG(Electroencephalography). It is one of the non-invasive techniques among many, like fMRI and PET. The brain's Scalp produces an Electrical signal. Depending on the electrode type, the electrodes are put on the Scalp using a well-known process. This approach yields a weaker and low-frequency signal than the ECoG signal. Another non-invasive technique is MEG. In the MEG **(Magnetoencephalography)** technique, the magnetic field due to brain activity is measured. This field is weak and difficult to measure using simple commercial magnetic sensors. This field is below 10^{-9} tesla, requiring a unique magnetic sensor. Traditionally two types of sensors are used to extract the MEG, 1) SQUID (Superconducting Quantum Interference Device) (Figure 1) and 2) OPM (Optically Pumped Magnetometer) (Figure 2). The SQUID is a Cryogenic sensor, requiring a temperature below 273°K. It is based on the superconductor and Josephson junction principle[15]. Another sensor is yet another research [16]. Both SQUID and OPM sensors are not cost-effective. Moreover, they are delicate to use. So, practical applications are complex. A new type of sensor combines an optical reflector with a hall effect sensor, as shown in figure 3. Fraternity is a source of optimism for biomedical stream researchers, particularly neuroscientists or neuropathy studies. This performance is also evaluated in ambulatory settings [1],[5].

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II. MATERIAL AND METHOD

A. Magnetic potential in the Scalp is related to the generation of speech

The dipole response formed by synaptic activity due to specific events, such as eye blinking, hand motions, or voice stimulation from various sources, generates the Scalp's electrical potential and magnetic field. The ERP ("Event-Related Potential") is the name given to this electrical potential. The ionic current generated by cation formation at the apical dendrites causes the ERP to be produced.

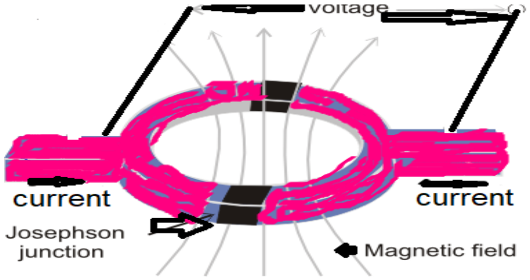

Figure 1 Squid principle

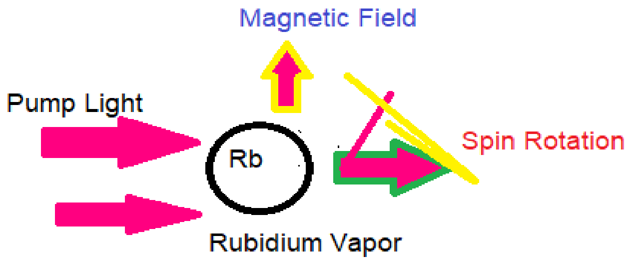

Figure 2 OPM (Optically Pumped Magnetometer)

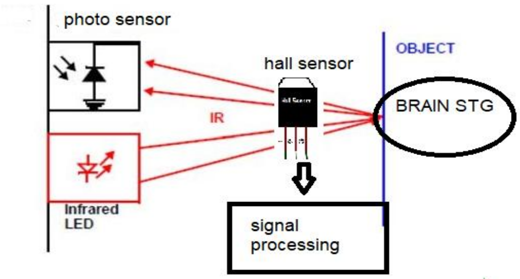

Figure 3 Hall effect sensor and Optical Source

The electrical potential of the Scalp is a good indicator of cortical function. A single electrode may provide a voltage equivalent to a 100million and one billion neurons. Frequency content, consistency, and recorded impact behavior may all be significantly differentiated by the varied electrode diameters and placements .. The advanced technique offers us improved scalp frequency and voltage. The Scalp data is not reliant on the electrode size since the potential is tightly space-normalized via "mass conduction" in the skull and the brain [6]. The potential created at the Scalp owing to speaking action is relatively modest. It is significantly polluted due to others. Therefore, mapping the exact location of the electric field due to imagined speech is crucial. This study minimizes the required number of electrodes and so the signal processing complexity. Since the EEG has an excellent temporal resolution but poor spatial resolution, mapping the area on the Scalp of imagined speech is difficult. The MEG technique are utilized for this task.

B. Electrodes

There is a Hall effect base magnetic-electrode with Laser light. It can easily measure the magnetic field of the optically reflected output. It is placed on Scalp near STG (Superior Temporal Gyrus) (Figures 3,4, 5, and 6) and rotated along a 3cm periphery to get the exact location by measuring PSD (Power Spectral Density).

C. Method

To map the location of the electric field (EEG) due to imagined speech MEG technique is used. Due to the excellent spatial resolution of MEG, mapping accuracy will be adequate. The sensor assembly contains a light source as a near-infrared LED and a tiny solid-state hall effect sensor to extract magnetic information of the imagined speech (figure 3). This sensor assembly is placed at seven different positions they are F3, C3, T7, T3, F4, C4, and T8. Number and location as per international 10-20 standard. The odd and the even numbers indicate the left and right side hemisphere locations, respectively. Eleven participants are right-handed with ages between 25 to 50 years. They were told to pronounce the vowel 'AEight times with a one-second break. The output of the sensor to an instrumentation amplifier with a high pass filter of 0.5 Hz and a low pass filter up to 2000Hz. This front-end output is connected to the C for further processing with the LABVIEW software from National Instruments. Adding a notch filter of 50 Hz and up to seventh harmonics removed the powerline noise. Frequency decomposing and independent component analysis removed all the artifacts, such as eye blinking, the ECG., and other EMG-based artifacts due to volume conduction by filtering the low pass filter of 100Hz. Usually, this kind of experimentation is done in a magnetically shielded room. Instead, a self-made Faraday's cage-type helmet is used. The helmet (Figure 7,8) was made using copper and mu-type magnetic material. The MEG is insufficient to measure and decode imagined Spectro-temporal speech features. The PSD (power spectral density) is plotted (figure 9). Here also, EEG is used to take further reading. The characterization was done for EEG.

III. ELECTRICAL FEATURIZATION

The impedance of the electrode was tested across a frequency spectrum of 5Hz to 100Hz. A typical Ag/AgCl wet electrode was employed as a reference electrode, and the other electrodes were placed at F7, T3, & C3 according to the usual 10 - 20 schemes. In addition, the standard Ag/AgCl (ground electrode) was inserted (Fig. 4). The outputs of the Ag/AgCl electrodes were monitored at a distance of 2cm from the dry contact electrodes. Two conventional instrumentation amplifiers ("INA333 TI and AD8233 Analog Devices") with earlobe reference were used to capture test and reference signals in parallel at a sampling rate of 512 samples/second. The test was conducted at room temperature (about 29°C) and 76 percent relative humidity. In addition, the contact resistance between the electrode and the skin was measured. All of the observations were carried out on a real-time signal.

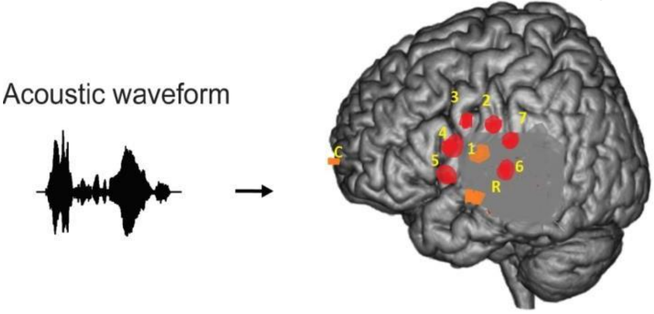

Figure 4: Location on the mapped

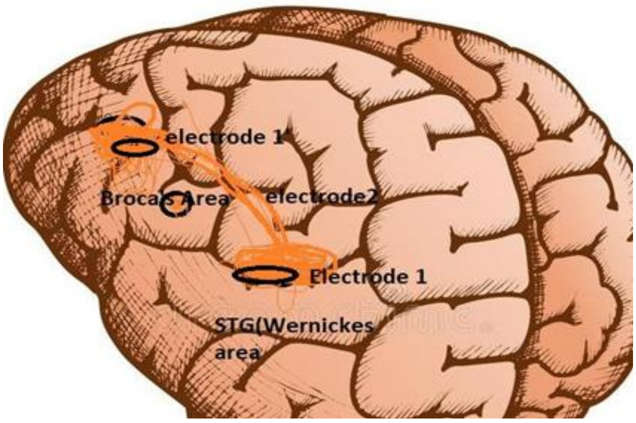

Figure 5 STG location on brain cortex

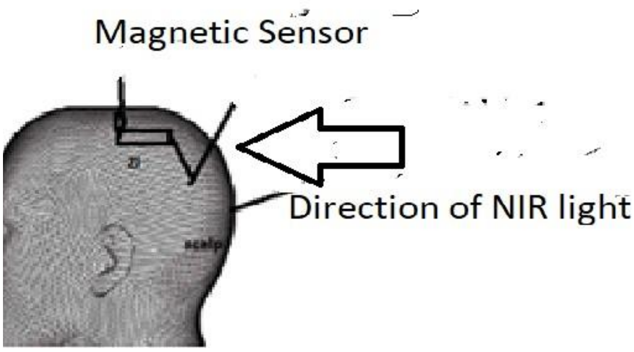

Figure 6 Position of the MEG Sensor

Figure 7 Helmet section

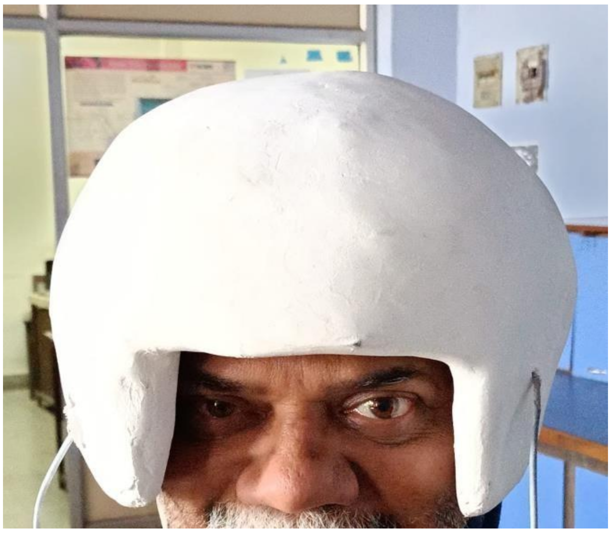

Figure 8 Helmet

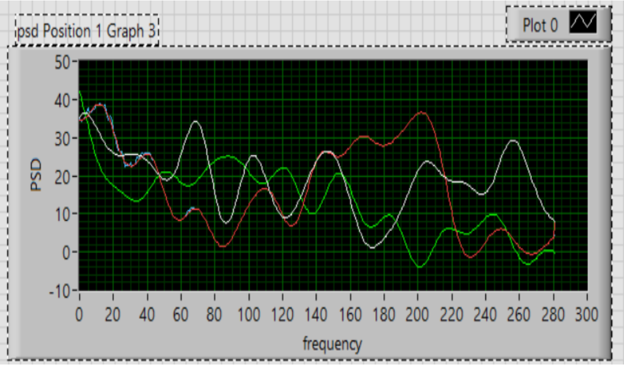

Figure 9 PSD of four different plotted

The open circuit's stable and repeatable potential is essential in constructing the amplifier's maximum gain, and signal drifts limit the "low-frequency" bandwidth. The mean open-circuit voltage of the Ag/AgCl electrodes was 200.8 mV. Three distinct electrodes, the graphene, spiky dry, and metal electrodes, were measured to have an average measure value of 252.8mV±10.0mV, 410.3mV±63.3mV, and 470.2mV ±100.7mV, respectively. The impedances recorded at the subject's head when four electrodes were placed are shown in Table 2. Except for the graphene electrode, the values of dry electrodes were much more significant than those for "Ag/AgCl" electrodes. Impedance fluctuations were seen on the dry electrodes. Different activities, such as alpha, beta, and eye blinking signals, were detected and quantified in the EEG waveform (Fig. 10: Eyeblink). The correlation coefficient and root mean square deviation were calculated for four participants based on their performance and other ERP for 60-second data patterns. The graphene and Ag/AgCl electrodes' values were similar (See tables 3 and 4). However, the eye blinking potential correlation coefficient was more extensive than that of other EEG potentials. As can be seen in Figure 9, PSD plots of alpha and beta waves from graphene electrodes were created for three different subjects.

IV. RESULT AND DISCUSSION

All measurements of the active and passive variables of the MEG and EEG electrodes fulfilled the requirements for recording EEG and MEG. The PSD of MEG gave the exact location of the electrode to be placed for EEG. The electrode's Spectro temporal properties were identical to wet electrodes in the low-frequency band of the beta region. Graphene electrodes performed similarly to wet electrodes in the gamma range. Other dry electrode findings did not meet the gamma range criterion. The RMSD and the "correlation coefficient" of graphene electrodes paired with the performance of wet electrodes are crucial measures in deciphering the speech signal. The eye-blinking performance was vital since ERP may be comparable to speech-generating potential and obvious artifacts for other tests. In signal processing, the eye blinking potential played an important role. The contacting impedance between the Scalp and the electrode is an important metric to consider while choosing an electrode for speech decoding.

At the same time, adequate electrode placement on the Scalp is essential. Comparing the passive parameters was crucial as it led to the optimal electrode selection for this study. This study aimed to use the EEG to decode the Spectro temporal characteristic of imagined speech and construct a wearable solution for speech-disabled people. Consequently, for better outcomes, the chosen electrode must meet all requirements. In terms of time & spatial distribution, the EEG of the intrinsic state is highly varied. The dry electrodes are compared in detail in Table 5. They're simple to employ in BCI and another wearable usage. Dry electrodes are ideal for a steady outcome due to their excellent and accurate geometry. This extensive information regarding brain activity gives critical spatial information. This information enabled the brain's electric field to be mapped from the cortex to Scalp in the existing and upcoming BCI applications. Due to capacitive behavior, dry electrodes are not suited for frequencies below 0.5Hz. The lower frequency limit varies by electrode type and is currently being worked out. Different kinds of dry electrodes are consistent with modern bio-signal amplifiers in theory.

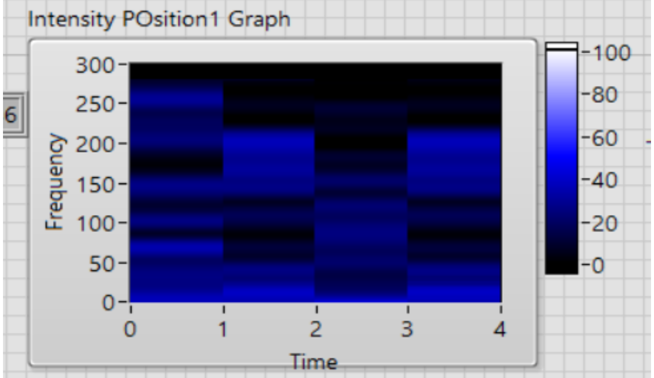

Figure10 Spectrogram

Table1 Average PSD with Position

Subject	**P1**	**P2**	**P3**	**P4**	**P5**
1	8.3	7.2	8.4	8.1	6.2
2	12.3	8.3	12.1	12.2	7.2
3	12.2	4	6	4.2	4.2
4	12.3	7.3	9.3	9.93	5.6
5	12.1	8.9	8.7	8.0	8
6	12.8	6.8	8.4	8.1	6.2
7	12.3	8.3	12.1	12.2	7.2
8	12.2	4	6	4.2	4.2
9	12.1	9.0	7.5	6.8	4.7
10	12.6	8.9	8.7	8.3	9

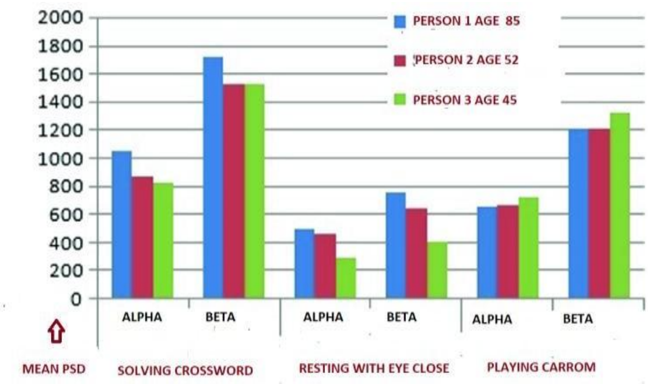

Figure 11: Mean PSD of 3 distinct subjects at various alpha and beta wave frequencies of 8 Hz and 14 Hz.

Table2: Mean RMSD of EEG data

Activity name in voltage (UV)	RMSD “Ag/AgCl Wet electrode	RMSD Graphene electrode	RMSD Metal electrode	RMSD spike electrode”
Beta	3.9 +/-.8	4.3+/-1.0	4.9+/-2.4	4.7+/-1.7
Alfa	4.8+/-1.2	5.1+/-1.4	6.3+/-3.4	5.7+/-1.9
Intrinsic EEG	4.7+/-2.5	5.4+/-0.6	6.9+/-3.4	6.1+/-2.0
Eye blink	5.8+/-2.3	7.2+/-2.5	8.3+4.5	7.5+/-2.8

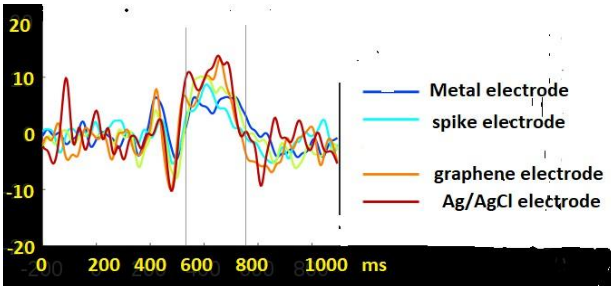

Figure 10: Eyeblink potential

Table 3: EEG data percentage correlation coefficient

Name of activity in percentage	**“Ag/Ag Cl Wet else**	**Graphene electrode**	**Metal electrode**	**spike electrode”**
Intrinsic EEG	60+/-14	62+/- 22	32+/-19	36+/-13
Eye blink	93+/-2.8	95+/-5.8	93+/-.5.6	91+/-6.9
Beta	85+/-4.5	79+/-4.6	72+/-6.9	83.+/5.9
Alfa	92+/-3.5	89+/-4.5	78+/-5.8	85+/-5.7

V. CONCLUSION

It may be concluded that specially design optical based magnetometer is able find imagined speech location on cortex area and can be mapped on scalp and "graphene-based electrodes" are better for utilizing the EEG to decode magined speech. Its high bandwidth, adaptability, low contact impedance, and other properties suit additional BCI applications. It's suitable for use as a wearable device for studying brain activity stop.

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