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Study on EEG Artifact Suppression and Polarity Classification in Electrotactile Stimulation*

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I. Introduction

This study investigates the effects of electrotactile stimulation on electroencephalogram (EEG) signals when applied to a fingertip. While electrotactile stimulation can evoke various tactile sensations by activating skin receptors, its high voltage can cause significant artifacts in EEG recordings. We examined methods for artifact suppression and explored the feasibility of classifying the polarity of electrotactile stimulation based on EEG responses.

There are two types of electrotactile stimulation: anodic and cathodic [1]. It is known that anodic stimulation produces low-frequency vibration sensations, while cathodic stimulation produces pressure sensations [2]. However, when testing with cathodic stimulation, the peripheral electrodes were at a high voltage over 100 V, and there was a high possibility that the difference in the human body potential would affect the EEG signals of several tens of μV. In other words, for more accurate measurements, such artifacts must be observed and investigated in detail.

In this study, we proposed connecting the peripheral electrodes to earth ground to reduce the potential difference between the electrodes and the human body during electrotactile stimulation (Fig. 1).

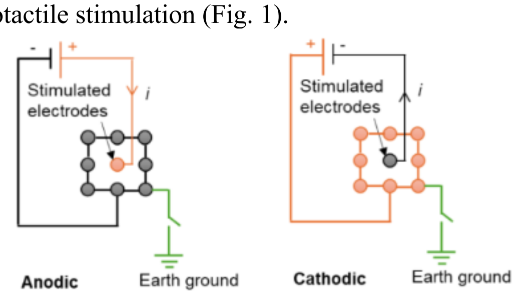

Figure 1. Simplified circuit diagram with or without earth ground connection

Typically, stimulation is applied only to the fingertip with closed loop of current flow; thus, it is not necessary to use ordinary earth ground to avoid the effect of high potential difference with the body. For example, for anodic stimulation, the current would flow toward the peripheral electrodes [Fig. 1 (left)]. However, for cathodic stimulation [Fig. 1 (right)], the high potential and larger area of surrounding electrodes may cause current to discharge into the body due to the potential difference, potentially leading to artifacts in EEG signals. Although some of the discharged current is attenuated by the body's tissue impedance, it may still appear as artifacts in EEG recordings. Also, in [3], while artifacts caused by the power supply were removed using a 50 Hz notch filter, the removal of artifacts caused by pulsed current was not discussed. Since the human body's potential is naturally close to earth ground, grounding the peripheral electrodes is expected to minimize these artifacts.

II. Experiment

In light of the above considerations, we define this study as an experiment to verify whether connecting an earth ground to the peripheral electrodes when using two types of electrotactile stimulation (anodic and cathodic), can reduce artifacts in the measured EEG signals and create an appropriate environment for EEG measurement. Furthermore, we investigate whether polarity classification between anodic and cathodic electrotactile stimulation can be feasibly achieved. This study was approved by the Research Ethics Committee of the Institute of Systems and Information Engineering, University of Tsukuba (approval number: 2024R842).

The electrotactile kit used in this study as the same as that described in [4]. It stimulates tactile receptors by passing an electric current through the skin. The electroencephalograph employed was the FLEX 2 Gel – 32 Channel Wireless EEG Head Cap System (FLEX 2 Gel), manufactured by EMOTIV. The current pulse used was also identical to that in [4], where two pre-pulses were applied for threshold estimation. As shown in Fig. 2, the stimulation duration was 200 ms for every second; therefore, it is expected that, during EEG measurement, artifacts occurring at every second (1 Hz) would be observed.

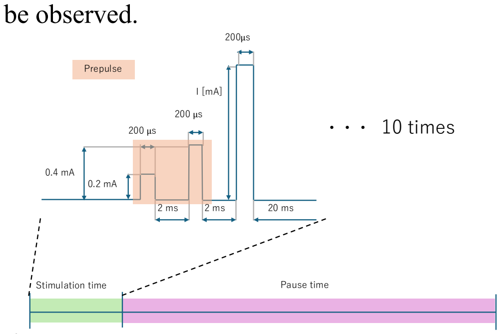

Figure 2. Pulse current of electrotactile stimulus used in this study

Electrical stimulation was administered to three healthy 22-year-old males with normal vision, motor function, and no

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mental illness. Stimulation was applied under four different conditions, combining polarity and earthing factors, presented in random order with two trials each. Thirty-two electrodes were used with the FLEX 2 Gel, following the extended 10-20 method layout with some sites omitted as shown in Fig. 3 (EmotivPRO's default layout). Participants were instructed to sit, close their eyes, and remain still while touching the electrodes of electrotactile kit for 180 seconds. This condition is considered to increase the proportion of alpha waves in the EEG signals compared to other frequency bands (particularly delta waves).

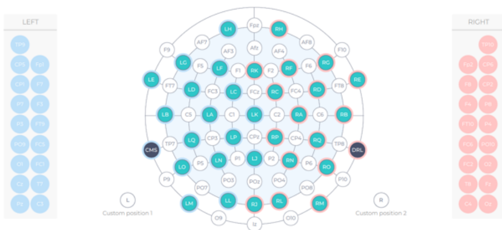

Figure 3. Electrode arrangement diagram for EEG measurement

III. Results and Discussion

The results shown in Fig. 4 were consistent across all participants and trials. In the case of anodic stimulation, there was little difference visually even when the earth ground was connected. But in the case of cathodic stimulation, the waves with an amplitude of approximately 100 µV, appearing at around 1 Hz, were no longer observed when the earth ground was connected.

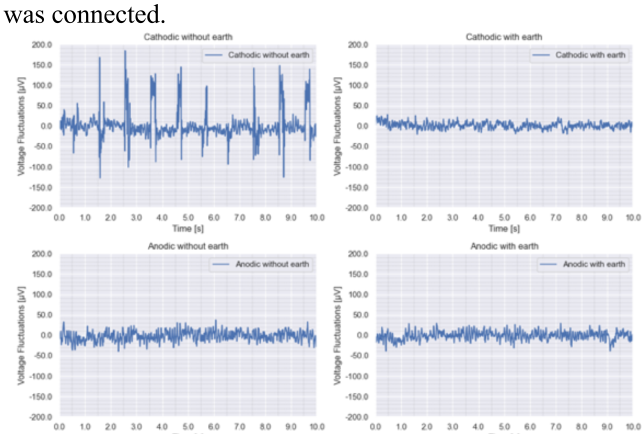

Figure 4. EEG signal (Cz) measured for 10 seconds following the perception of the electrotactile stimulus.

After applying FFT to the EEG signals, the relative amplitudes of delta (0.5–4 Hz), theta (4–8 Hz), alpha (8–13 Hz), and beta (13–30 Hz) waves were calculated as ratios to the total amplitude across all frequency bands. These ratios were then averaged across the 32 electrodes. Fig. 5 compares the proportions of delta and alpha waves across the four conditions. A Wilcoxon signed-rank test was conducted to compare the effect of anodic and cathodic stimulation with and without earth ground on EEG band ratios. The results showed a significant difference between the cathodic-without-earth and cathodic-with-earth conditions for delta waves ($Z = -2.201$, $n = 6$, $p < .05$) and alpha waves ($Z = 2.201$, $n = 6$, $p < .05$), but no significant differences between anodic-without-earth and anodic-with-earth conditions. No significant differences were observed for theta or beta waves across the four conditions.

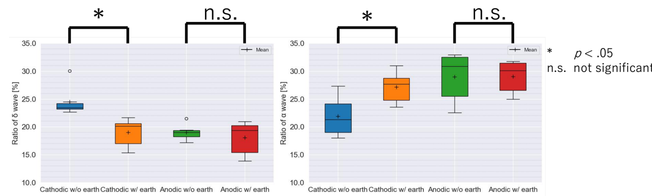

Figure 5. Comparison of delta and alpha wave ratios across four conditions

Next, using the measured data from which the earth ground was connected (anodic-with-earth and cathodic-with-earth), we applied machine learning (ML) to determine whether the EEG data corresponded to anodic or cathodic stimulation. TABLE I. shows the classification result for stimulation polarity. Both analyses were conducted using the same parameters. EEG segments (3.0 s window, 1.0 s step) were extracted at 256 Hz. A 64-unit long short-term memory (LSTM) layer was used. In the attention-based model, the LSTM layer was followed by an attention mechanism, global average pooling, and a fully connected layer with one unit and sigmoid activation. In the model without attention, the last hidden state of the LSTM was directly connected to the fully connected layer. Both models were trained for 10 epochs with a batch size of 32 using the Adam optimizer. Performances were evaluated using leave-one-out cross-validation (LOOCV). The attention-based model provided high accuracy of 98 %.

TABLE I. Results of Classifying the Polarity of Electrotactile Stimulation

ML Algorithms	Accuracy	Precision		Recall	
		anodic	cathodic	anodic	cathodic
LSTM+LOOCV	0.59	0.59	0.59	0.59	0.58
LSTM+LOOCV+Attention	0.98	0.98	0.98	0.98	0.98

IV. Conclusion and Future Work

This study explored reducing EEG artifacts from polarized electrotactile stimulation and classifying stimulation polarity via EEG. Connecting peripheral electrodes to earth ground effectively suppressed artifacts, particularly from cathodic stimulation. LSTM with LOOCV and Attention proved effective for polarity classification. Future work will explore other suppression techniques and EEG responses under cleaner conditions.

References

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