High Gamma Band Activity in Noninvasively Measured EEG Preceding Anti-saccade Initiation

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***Abstract*—A potential for detecting high gamma band (HGB) activity from scalp EEG is explored by employing a high input-impedance electroencephalograph for the measurement. An anti-saccade task was designed to elicit motor-related HGB activity. As a result, we confirmed increased power of HGB (100-105 Hz) preceding the anti-saccade initiation in all three subjects. A common timing of the power increase was observed at 50% point of mean reaction time of anti-saccade for each subject.**

Keywords—high gamma band; electroencephalogram; brain computer interface; motor related potential; anti-saccade

I. INTRODUCTION

The frequency band ranging from 60 to 250 Hz of electroencephalogram (EEG) or electrocorticogram (ECoG) is called high gamma band (HGB). HGB activity is highlighted as a promising input signal for brain mapping and brain-computer interfaces (BCI). Edwards et al. reported the HGB oscillation (60-250 Hz) in auditory association cortex in response to deviant auditory stimuli [1]. Ray et al. confirmed greatest increase in the HGB activity (80-150 Hz) of event-related potentials over auditory cortex and somatosensory cortex during selective attention [2]. Ball et al. [3] indicated existence of movement related HGB (50-128 Hz) and Miller et al. [4] showed the usefulness of the HGB activity (76-150 Hz) for movement classification. Since all of these activities are recorded invasively using intracranial electrodes, bandwidth extension is called for the current measuring electroencephalographs. However in current instrumentation, high frequency cortical activity can be significantly attenuated by intervening cranial tissues during scalp recordings[5], [6].

On the other hand, Kimura et al. addressed noninvasive measurement of high-frequency scalp EEG (>100 Hz) by enhancing input impedance of the electroencephalograph, and succeeded in detecting somatosensory-evoked high-frequency oscillations (450-750 Hz) [7]. Since the lower the frequency is, the higher the input impedance becomes, it is highly expected that electroencephalograph bearing similar input impedance to that in the article [7] can measure HGB activities of EEG noninvasively from the scalp. In this paper, we explored a potential for detecting HGB activities from scalp EEG measured with a high input-impedance electroencephalograph.

II. MATERIALS AND METHODS

2.1 Setup and Experimental Task

Three healthy male subjects aged 22 or 23 years old participated in the experiment. Each subject was seated in front of a target composed of 3 horizontally aligned red LEDs. The target was placed directly in front of the subject's eyes at a distance of 600mm so as to locate the left and right LEDs at a 15^{O} angle from the center. A shielding tent covered the subject, LEDs and the instrumentation to minimize the effect of power-line noise and the experiment was conducted in a dark room to remove external visual stimuli. Fig 1 shows a block diagram of the experimental setup.

The experiment involves the performance of an anti-saccade task, where the subject is instructed to actively gaze in the opposite direction from the target visual stimulus. An anti-saccade task was chosen over a saccade task for two reasons: The anti-saccade task is less susceptive to the generation of visual evoked potentials (VEP) due to the target LED. Additionally, the anti-saccade task involves voluntary oculomotor control, which requires more brain activity than passive saccadic target following.

The anti-saccade task was performed by the following procedure illustrated in Fig. 2:

1) The visual target in the center is lit the subject

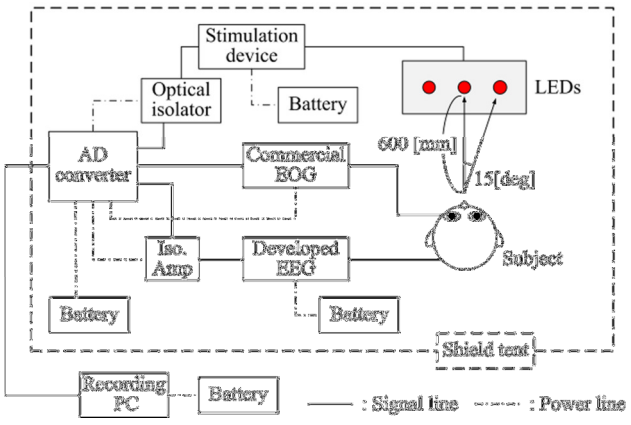

Fig.1. Experimental setup

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fixates his gaze on it.

2) *After a random interval of 2-5 sec the visual target in the center is turned off while either the left or the right LED is turned on.*

3) *The subject must then fixate his gaze in the opposite direction of the lit target for the duration of the stimulus (1sec).*

4) *The visual target that was presented is turned off and replaced by the original central fixation target..*

5) *The subject returns his gaze on the central target for another random 2-5 second interval.*

Five sets of 40 trials as described were carried out with 20 trials each for the left and right stimulus. A rest period of 10 min was included between each set to reduce fatigue and preserve the subject's concentration. For each set the order of right and left trials were randomized to prevent the subjects from predicting their response.

2.2 *Measurements and Instrumentation System*

Two main measurements are recorded as the subject performs the experimental task: electrooculography (EOG) and EEG. The shield tent in which the subject and the instrumentation are contained (SR-403T, made by Tokyo Keiki Aviation) is grounded along with the rest of the instrumentation to reduce noise. Additionally, all the instrumentation is battery powered.

EOG is performed to obtain information about the change in direction of the subject's gaze. We used a commercially available EOG instrument (EOG100C, made by BIOPAC Systems) with 4 disposable wet electrodes (NE-121J, made by Nihon Kohden) located above and below the right eye; and left and right of the eyes respectively. The instrument was set to 60dB gain, 0.05 Hz high-pass filter and 35 Hz low-pass. The EOG data is then digitized at 25kHz sampling frequency (ADC MP150, BIOPAC Systems).

Five Ag-AgCl electrodes were used for the EEG system placed according to the international 10-20 system. Three recording electrodes are placed at Fz, Cz, and Oz. The right earlobe (A1) was used as reference electrode and Fpz, as ground. EEG is measured simultaneously with EOG and digitized through the same ADC with the addition of an isolation amplifier to prevent noise due to ground loops.

Fig.3 shows a high-frequency electroencephalograph developed. For the first stage instrumentation amplifier we used an IC with a nominal input resistance of 10TΩ. (INA116). This IC contains guard rings around the input terminals of the instrumentation amplifier, leakage current. Furthermore, we suppress the reduction of the input impedance at high frequencies by using shielded cables from the electrode and actively driving the shields with the output of buffers recording from the guard rings. The gain of entire device is 86 dB for the frequency band is 1 ~ 3000 Hz. We use three of

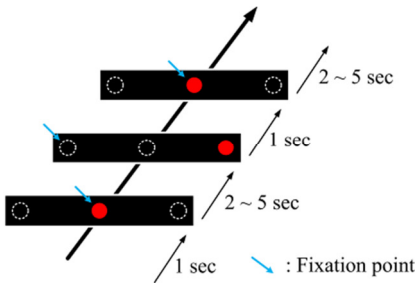

Fig.2. Flow of Anti-Saccade task

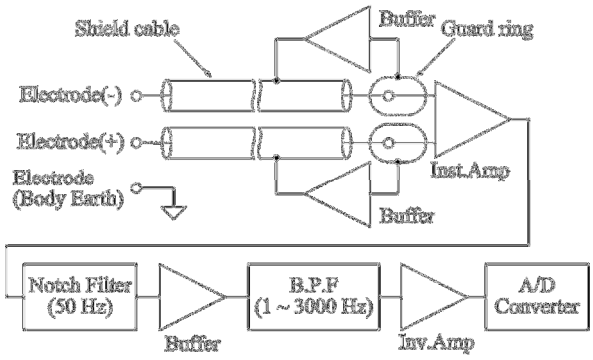

Fig.3. Block diagram of the developed EEG instrument

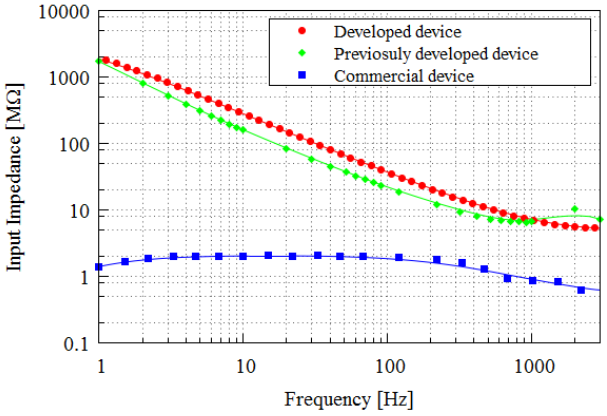

Fig.4. Input impedance vs Frequency

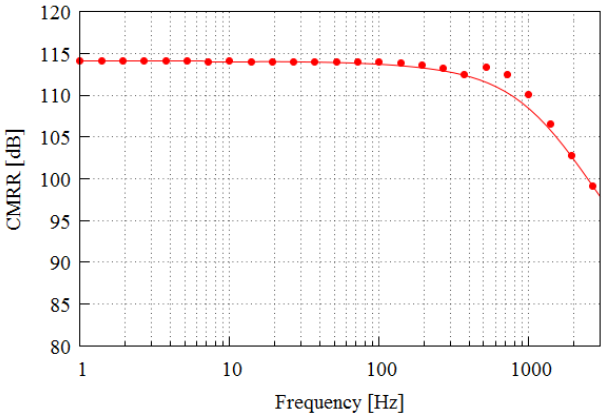

Fig.5. CMRR vs Frequency

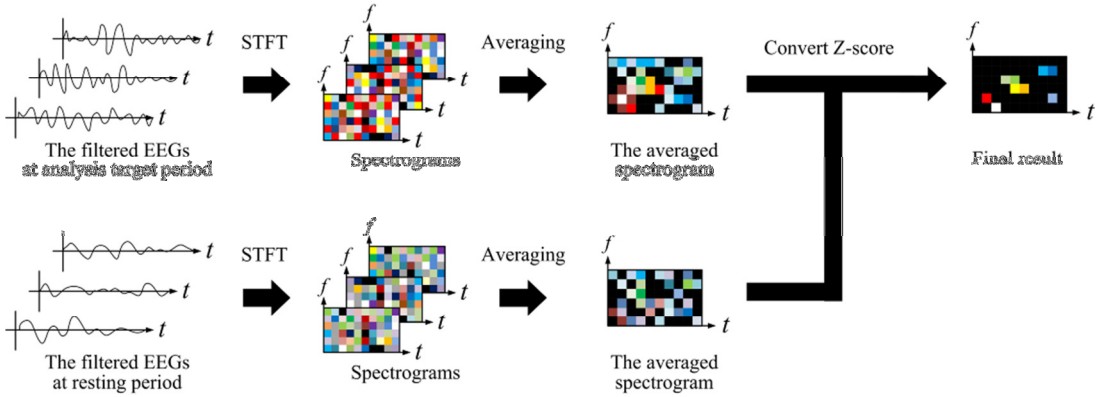

Fig.6. Flow of time-frequency analysis

these devices for the measurement to obtain simultaneous measurement of 3 channels.

Fig.4 shows the input impedance vs frequency of our high-frequency electroencephalograph. The developed device has higher input impedance over a wide frequency range compared to a typical commercial device (ERS100C, made by BIOPAC Systems). Therefore, we conclude that we can detect weaker signals at those frequency bands. Moreover, this newly developed device has higher input impedance than the one we developed and demonstrated in a previous report [7].

Fig.5 CMRR vs frequency of the first stage instrumentation amplifier in our high-frequency electroencephalograph. The developed device has a measured CMRR of more than 110dB from 1 Hz to at least 700 Hz. We considered that official CMRR of the IC is 80dB, have adequate CMRR. It is desired to further increase the value of CMRR, but it was not possible from the relationship that requires high input impedance, and selects the instrumentation amplifier having a large CMRR.

2.3 Offline Analysis

In this study, we performed offline time-frequency analysis to examine the frequency band that is activated during the task (Fig.6), and full-wave rectification integral processing to investigate deeper components activated. Additionally, we calculate eye movement velocity by differentiating the EOG signal before each analysis. Then, trials in which eye blinking artifacts prevented the recording of EOG activity were excluded from the rest of the analysis.

2.3.1 Time-frequency analysis

Initially the data was bandpass filtered to remove excess noise. The frequency band was set to 70 ~ 200 Hz from the preceding reported cases. Then, we applied the short-time Fourier transform (STFT) for the data of analysis section using a Hamming window, of 100 ms width, and 95 % overlap. Then we performed a synchronized event based averaging based on the start time of the SC to the data obtained by applying the STFT. The start time of the SC is the time when the eye movement speed exceeds 50 rad/sec. We averaged a total of 140 event based recordings per subject. Finally the data was converted to Z-score values of power to compare the data during the rest (control-fixation before and after the anti-saccade task) with the event based average. Data at rest was

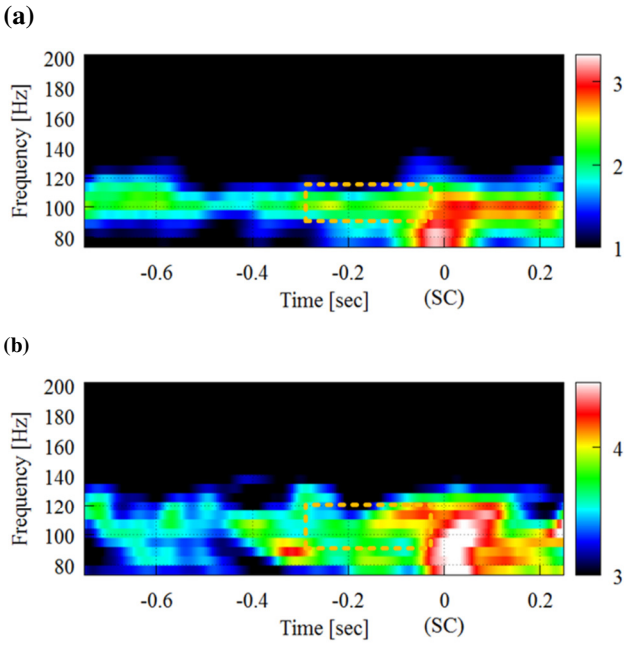

Fig.7. Result of time frequency analysis of EEG at Cz.
(a) Subject A. (b) Subject B

also filtered, STFT, synchronous event based averaged in the same manner to obtain a consistent control signal.

2.3.2 Full-wave rectification integral processing

For the second phase of the analysis the data was first bandpass filtered for the range 100 ~ 105 Hz. This frequency band was pre-determined from the results of the time-frequency analysis. Then we applied synchronized event based averaging based on SC data. In the manner described before for the same 140 trials per subject. After the averaging, rectification is done by taking the absolute value of the data and integrating it with a 10ms time constant. Finally, it was converted into Z-score values of power to compare the rest data with the rectified-integrated anti-saccade task data. As in the previous case, rest data had the same pre-processing.

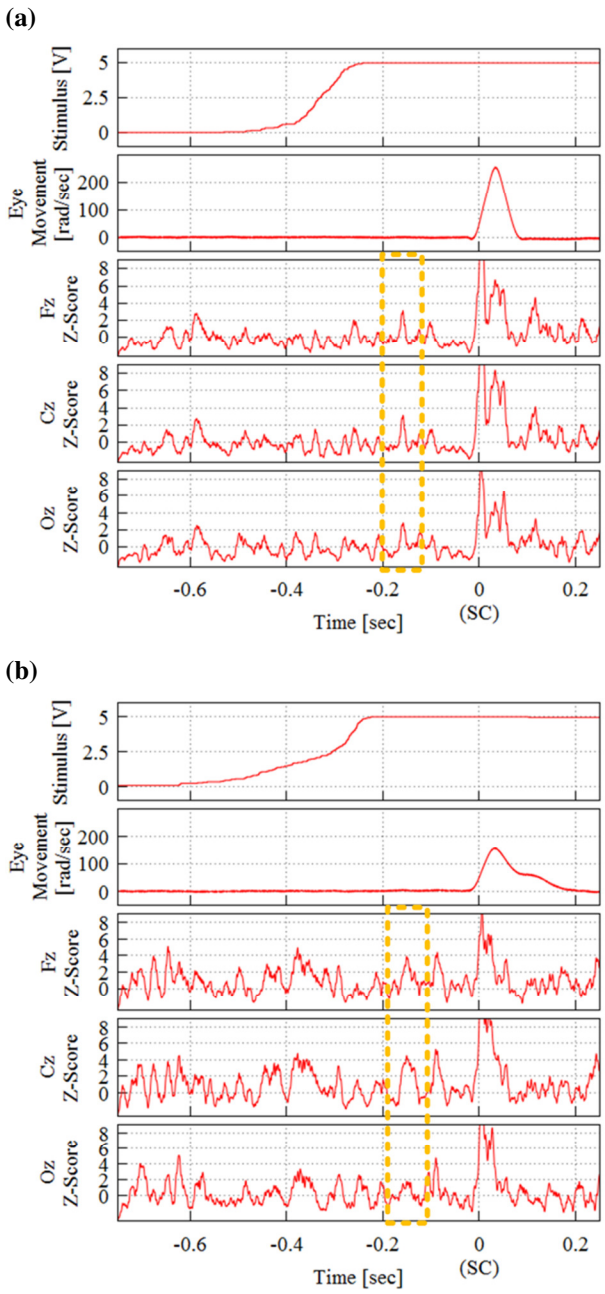

Fig.8. Rectification and integration analysis results.
(a) Subject A. (b) Subject B

III. RESULTS

Fig.7 (a) shows the spectrogram of the results of the time-frequency analysis in Cz electrode position of Subject A. The value of the power is converted to Z-score, a value over 2 is a reaction of significance. 0 sec is the time of the SC start. The average time of presentation of the visual target Subject A is about -0.330 sec. Power's increases rapidly in around 0 sec, it is due to influence of the SC. We it can be seen that the power is increasing around the 95 ~ 110 Hz between the SC to start from the presentation after the target. Fig.7 (b) shows the spectrogram of the results of the time-frequency analysis in Cz electrode position of Subject B. The average time of presentation of the visual target Subject B is about -0.304 sec. In subject B, the value of the Z-score is greater, for of the noise level is larger than the subject A. However, similarly A, we it can be seen that the power is increasing around the 95 ~ 110 Hz between the SC to start from the presentation after the target. This reaction was also seen in subjects C. It was confirmed that therefore are appearing in common to all subjects. Consequently, analysis was performed by narrowing to 95 ~ 110 Hz around is performed next band in the full-wave rectification integral processing.

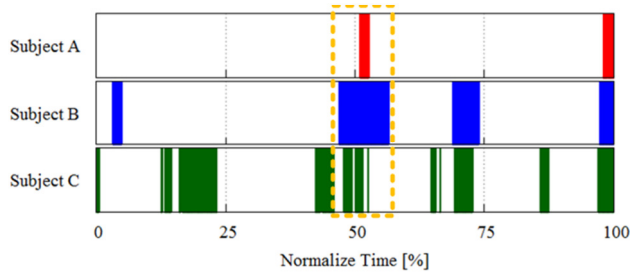

Fig.9. Significant increase in band activity periods at Cz

Fig.8 (a) shows the waveform of the result of the full-wave rectification integral processing of Subject A. Stimulus (top) is the event averaged applied voltage to the LED for the target presented. We consider the start of the task trigger to be the point where the voltage crosses 2.5V as it is the average onset of LED switching Eye Movement shows the state of the SC, we have decided to point 0 sec of 50 rad/sec. Amplitude Fz, Cz, the Oz is converted to Z-score, the value over 2 is a reaction of significance. We note a rapid power increase at around 0 sec in the same manner as the time-frequency analysis due to influence of the SC. A significant pre-motor HGB event is confirmed by around the -0.15 sec in the results of Subject A.

Fig.8 (b) shows the waveform of the result of the full-wave rectification integral processing of Subject B. Reaction with significance was confirmed in around the -1.5 sec and around the -0.9 sec in the results of Subject B. Reaction of the significance of -1.5 seconds is confirmed in common both subjects A and subject B. However, significant reaction of -0.9 seconds is not confirmed in the subject A. The results of subject C, the reaction of significance had appeared a lot or not due to the influence of the noise. Furthermore, the Reactions that are common of the subject A and subject B is not confirmed. It was possible to identifying reaction of significance even in all subjects. However, we were no commonality in the reaction time.

We considered that because of individual differences in exercise capacity for each subject, differences arise when you compare the reaction time equally across subjects and trials. For this reason, it is normalized as a percentage of the time interval from the presentation of the target to the SC onset. Fig.9 Compares the results of the all the subjects with the normalized data by showing a vertical line during the times of significant activity in electrode Cz. 0% is the time of target presented, 100% is the start time of the SC. We can confirm

that there is a reaction of significance at around of 50% in all subjects. Furthermore, we have observed similar results also in Fz for this analysis. Reaction of significance has appeared in more Subject B and Subject C. We considered this is because the synchronization addition and averaging is not done well waveform of the SC is distorted and is not accustomed to Anti-Saccade task.

IV. Discussion

In this experiment we carefully controlled the effect of confounding variables by chosing an anti-saccade task. The task should be less affected by VEP artifacts since the subject's gaze (and consequently their foveal area) is directed away from the visual stimulus. By performing this experiment in a dark room without any other visual stimulus we isolate the oculomotor task. Additionally, we can confirm that the result is not based exclusively in visual processing because the effect presents itself in the central region (between frontal and parietal) at Cz and not in the occipital region (Oz) where the visual cortex is located. Also, VEP latencies very between subjects but the latency for the effect observed in this study is almost the same in all three subjects. Finally if the high gamma band eeg signal demonstrated were coming from an external source then it would not show up after the Z-score comparisson between the rest and task data.

In Fig.7, the power increased for the signal band between 95 ~ 110 Hz (high gamma band) from the time of the onset of the anti-saccade. Analyzing the 100 ~ 105Hz band with "Full-wave rectification integral processing" shows a significant increase in the power in all channels and for all subjects at around 0.2 seconds before the onset of the saccade. From this figure we can also see the average latency between the presentation of the stimulus and the eye movement.

The detection of the high gamma band activity in Cz is significant as it implies this effect is related to motor cortex activity. There exist variations in the precise frequency band of similar reported high gamma band activity, but the coinciding of the location timing and agreement across all subjects warrants further studies involving more spatial resolution and a higher number of subjects.

In this study the dynamics of the task occur very quickly. The time between the trigger and the eye movement is only 300 msec on average. We were able to detectable temporal changes in the EEG, using 100 msec as the window width of STFT. However, the frequency resolution becomes coarse because window width is narrow. Given the impracticallity of further increasing ADC sampling rate, it is necessary to optimize the appropriate window size for maximal spatio-temporal resolution in this experiment by using wavelet transforms.

Another alternative to increasing the study's power in the frequency domain, is to use independent component analysis (ICA) as a method of detecting spatial features of the waveform. It is possible to perform a better separation of signal and noise by rejecting spatial signals from non-motor areas, or signals correlated to muscle and blinking artifacts. However in order to perform spatial filtering through ICA, it would be necessary to increase the number of channels in the developed instrumentation system.

V. Conclusion

In this study we measured high frequency EEG during an anti-saccade task using our own developed EEG instrumentation. We observed a significant activity in the Cz at the average saccade onset time in all the subjects. This is a novel observation high-gamma band activity in an experimental task. Additionally our device enables us to perform high gamma band measurements usually only possible in ECoG studies. The experiment can benefit from further increase in the EEG device SNR and input impedance.

In future studies we plan to increase the number of channels of the developed high frequency EEG to obtain better spatial data, obtain precise electrode locations in the anatomy, perform further signal processing such as ICA and source localization to provide further insight into functional brain mapping.

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