Amplitude Modulation of Alpha-band Rhythm Caused by Mimic Collision: MEG Study*

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Abstract— Detection of a collision risk and avoiding the collision are important for survival. We have been investigating neural responses when humans anticipate a collision or intend to take evasive action by applying collision-simulating images in a predictable manner. Collision-simulating images and control images were presented in random order to 9 healthy male volunteers. A cue signal was also given visually two seconds before each stimulus to enable each participant to anticipate the upcoming stimulus. Magnetoencephalograms (MEG) were recorded with a 76-ch helmet system. The amplitude of alpha band (8–13 Hz) rhythm when anticipating the upcoming collision-simulating image was significantly smaller than that when anticipating control images even just after the cue signal. This result demonstrates that anticipating a negative (dangerous) event induced event-related desynchronization (ERD) of alpha band activity, probably caused by attention. The results suggest the feasibility of detecting endogenous brain activities by monitoring alpha band rhythm and its possible applications to engineering systems, such as an automatic collision evasion system for automobiles.

I. Introduction

Animals, including human beings, subconsciously avoid collisions. Collisions are seen to be negative (dangerous) events for survival. Recognizing collision risk and avoiding collisions are therefore important behaviors. It has been shown that pigeons and house flies have neural systems for rapid responses against expanding light [1, 2]. Humans can react to a collision in 80 ms or less [3], and the responses to collisions are not habituated [4]. These previous studies suggest that humans also have some neural systems specialized for recognizing and evading collisions. We have

therefore been investigating neural responses when humans anticipate a collision or intend to take evasive action by applying collision-simulating visual stimuli in a predictable manner.

Responses to emotional stimuli seem to be similar to those to collisions, since they are also primitive responses and are not habituated [5]. A similar study using emotional visual stimuli showed that anticipation of negative (unpleasant) images suppresses alpha-band rhythm in visual and right frontal cortices, suggesting top-down control by the right frontal cortex to the visual cortex [6]. In this study, we mainly focused on spontaneous brain activity with alpha-band rhythm. We presented participants with a collision-simulating image with a prior cue signal and recorded a magnetoencephalogram (MEG).

II. Experiment

Written informed consent was obtained from each participant prior to the experiments in accordance with the local ethical committee regulations.

A. Stimuli

A form that expands rapidly while maintaining shape is recognized as a collision [7]. Each participant was presented with a visual collision-simulating stimulus in which a black indeterminate form expanded on a grey background (Fig. 1 A: collision-simulating) in 170 ms, that is short enough to prevent saccade [e.g., 8]. As controls, two kinds of stimuli were also presented: one was a uniform background, the brightness of which decreased with time (Fig. 1 B: darkening), and the other was a black indeterminate form that changed in

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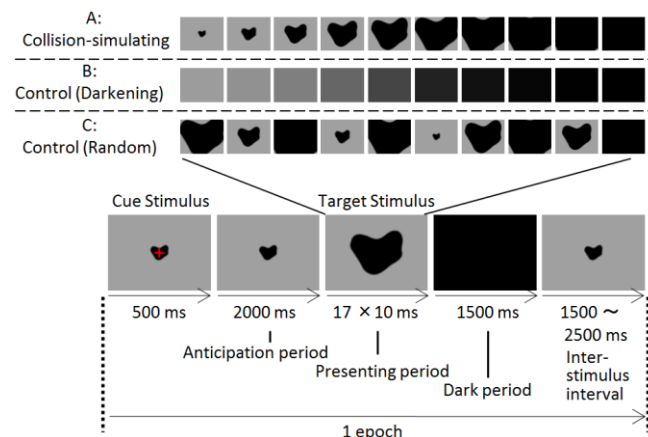
Figure 1. Schematic diagram of stimuli

size in a random manner (Fig. 1 C: random). Each target (collision-simulating or control) stimulus consisted of ten frames, each of which was presented for 17 ms, i.e., frame rate of 60 Hz. A cue signal, colored cross, was given visually two seconds before each stimulus. The color of the cross corresponded to the upcoming stimulus to enable each participant to anticipate the upcoming stimulus. Therefore, each epoch consisted of "anticipation period" between the cue and the target stimulus, "presenting period" during the target stimulus, and "dark period" after ending the target stimulus. Inter-stimulus interval was set randomly between 1.5–2 s. To keep the attention of each participant, an oddball stimulus was also presented. Each participant was instructed to count the number of appearances of oddballs and inform the number after each session. One experimental session included 120 epochs per stimulus, in random order. A total of 360 epochs and several oddballs were presented in separate six sessions. The stimuli were presented on a back projection screen located at 50 cm in front of the participant. The visual angle was 30 degrees in height and 40 degrees in width including the gray background.

B. Recordings

MEG signals were recorded with a 76-ch helmet system (Elekta-Neuromag, custom-type) from 11 healthy male volunteers (mean age: 24.6 years, standard deviation: 3.8 years). The passband was from 1 to 200 Hz, and the signals were sampled at 600 Hz.

C. Analysis

We merged the MEG signals of the six sessions at first. We then created a template of transient responses by time-averaging the MEG signals over epochs, and we extracted spontaneous rhythms by subtracting the template from the merged signal. We tried wavelet-transform analysis on the extracted MEG signals to survey time-frequency characteristics. Morlet's wavelet function with m=7 was applied as the mother wavelet. We also filtered the extracted MEG signals with a pass-band of 8–13 Hz and created envelopes by applying Hilbert transform. We averaged the obtained envelopes over epochs separately for each stimulus condition (collision-simulating or control) excluding the oddball epochs.

The amplitude of the alpha-band rhythm of each channel, which is described by the envelope, is assumed to have a maximum in the "dark period", because no visual stimulus was presented (Fig. 1). We therefore selected eight channels that detected the largest amplitude during the "dark period" and averaged the envelopes over the eight selected channels.

We analyzed the amplitudes of alpha-band rhythm of each participant within three time windows. We divided the "anticipation period" into two time windows, early (① -2 – -1 s) and late (②-1–0 s) periods, by analogy with studies on contingent negative variation (CNV). That is, it has been shown that orientation response (O-wave) appears following a warning (cue) signal and that expectation response (E-wave) appears prior to an imperative (target) signal in CNV studies [e.g. 9, 10]. Eliminating the time window between 0-1 s, in which responses to exogenous visual stimuli are dominant, we analyzed the alpha-band rhythm within the time window of ③ 1–1.5 s in the "dark period". In these time windows, 0 s means the onset of target stimuli.

We time-averaged the envelopes within each time window and evaluated the averaged value with one-way ANOVA followed by Tukey's multiple-comparison tests. The level of statistical significance was p < .05.

III. RESULTS

A. Transient response

Figure 2 shows a typical example of transient responses to the cue and collision-simulating stimulus of one subject (S6). Peaks after the onset of the target stimulus were clearer than those after the cue onset, probably because the brightness or shape change at cue onset was not so drastic. The topography of the magnetic field responding to the collision-simulating stimulus shows a typical dipolar pattern, and the source was located in the visual cortex in the occipital area. Comparing with transient responses to the cue and control stimulus, no significant difference in amplitudes or latencies of the transient peaks was found between conditions. Furthermore, the collision-simulating stimulus did not give rise to any specific transient peaks.

B. Time-frequency analysis

Figure 3 shows typical results of time-frequency analysis by wavelet-transform of another subject (S2). For simplification, only results averaged over 8 channels of the right and left occipital areas are shown. Spontaneous rhythms of alpha band (8–13 Hz) are predominant and modulated by the cue and target stimulus. Rhythms of other frequency bands are not clearly observed. Most of the results of time-frequency
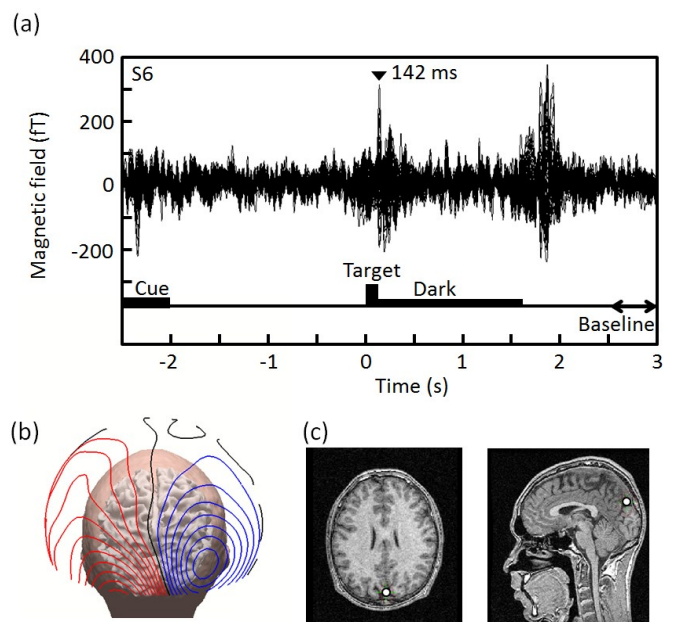

Figure 2. (a) Transient responses of one subject (S6). All channels filtered with 1-20 Hz are superposed. (b) Contour map of back view (interval of 25 fT) and (c) source locations estimated as a single current dipole (g-value of 98%) at 142 ms from the onset of target (collision-simulating) stimulus.

analysis similarly show notable alpha band activity. Therefore, we decided to focus on analysis of alpha-band rhythm. Alpha-band rhythm is observed over the occipital area and it is activated when no visual stimulus is presented in general. We therefore selected sensors that detected the largest amplitude of alpha-band rhythm during the "dark period". Figure 4 shows examples of the contour maps of amplitude of alpha-band rhythm during the "dark period" and selected channels for further analysis. The sensors that are sensitive to alpha-band rhythm are mostly located in the occipital area.
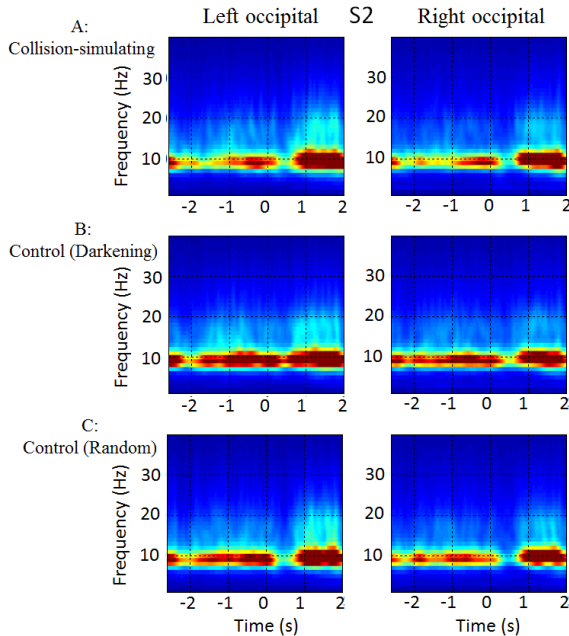

Figure 3. Examples of time-frequency analysis by wavelet transform. Results for occipital areas of both hemispheres of a subject (S2) are shown.
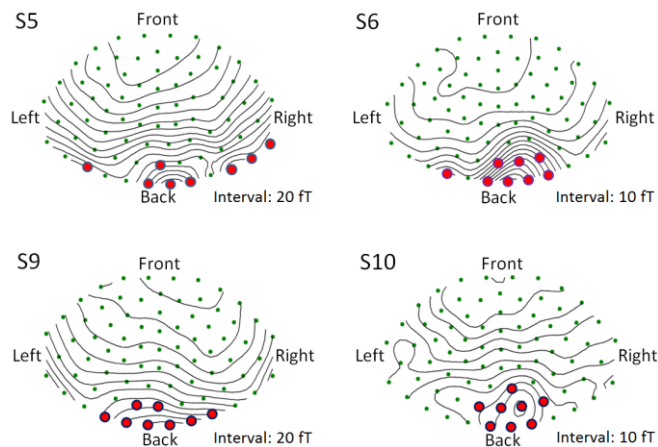

Fig. 4. Examples of amplitude distributions of alpha-band rhythm during the "dark period". Red circles indicate selected channels, which are sensitive to alpha-band rhythm, for statistical analysis.

C. Amplitude of alpha band rhythm

We eliminated MEG data for two subjects because of excessively large noise. Subject number of remaining 9 is still enough for even statistical analysis. The amplitudes, that is, the envelopes given by the Hilbert transform, of alpha-band (8–13 Hz) rhythm averaged over the 9 subjects (mean age: 25.1 years, standard deviation: 4.1 years) are shown in Figure 5. Amplitude of the rhythm remained almost constant between the cue and target stimuli (time windows ① and ② during the "anticipation period"). Just after the onset of target stimuli, the amplitude decreased and then increased dramatically. The amplitude then plateaued around 1-1.5 s from the onset of target stimuli (time window ③ in the "dark period"). Amplitude of the random control increased most belatedly. This delay is probably because the brightness of the random control image changes rapidly, while the brightness of the other two images gradually.

The statistical analysis showed that the amplitude of alpha band rhythm attributed to the collision-simulating stimulus was significantly smaller than that of the control stimulus in the anticipation periods (Fig. 6 ①: A<B, p=.043; A<C, p=.016, Fig. 6 ②: A<B, p=.046, where A, B, and C mean stimuli of collision-simulating, control of darkening, and control of random, respectively). On the other hand, in the plateau in the dark period, although a main effect of condition appeared (p=.04) in ANOVA, no significant difference was observed between conditions by a multiple-comparison test (Fig. 6 ③: n.s.).
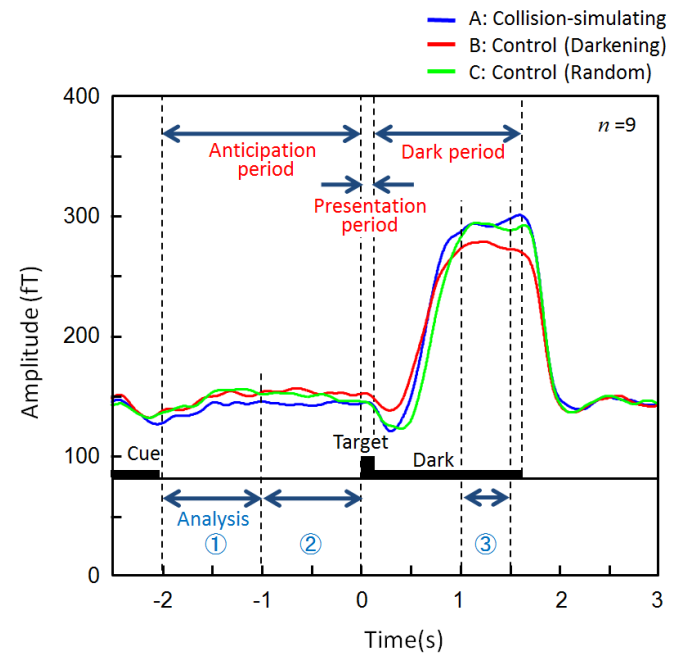

Figure 5. Time course of amplitude of alpha band rhythm grand-averaged over 9 subjects. Time windows used for statistical analysis are also shown (see Fig. 6).
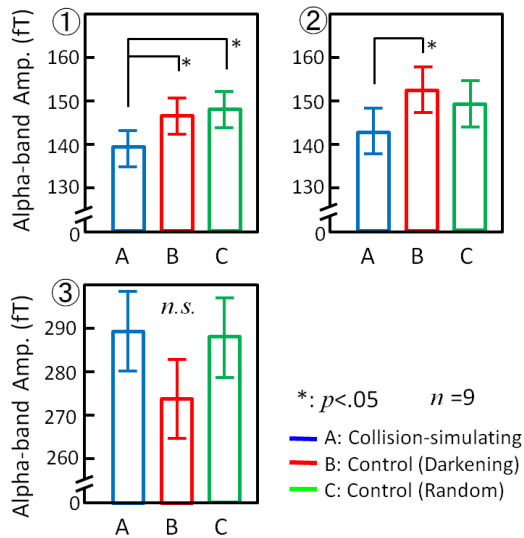
Figure 6. Results of group-level statistical analysis of amplitude modulations of alpha-band rhythm. ①: -2－-1 s of early anticipation period, ②: -1－0 s of late anticipation period, ③: 1－1.5 s in dark period.

IV. DISCUSSION

The results showing that alpha band rhythm occurred in the occipital area (Fig. 4) and was modulated dramatically by visual stimuli (Fig. 5) agree with results of previous studies [e.g., 11]. Furthermore, the alpha band amplitudes during anticipation were significantly different between collision-simulating stimulus and control stimulus. The difference was detected by the sensors that were sensitive to alpha-band rhythm.

In the anticipating period, i.e., time windows of ① and ②, the same stimulus was presented to each subject regardless of the upcoming target stimuli. Thus, the difference is caused by endogenous brain activity, and anticipation of a negative (dangerous) event induces larger event-related desynchronization (ERD) of alpha-band rhythm. Amplitude modulation of spontaneous brain activity by anticipating somatosensory or auditory stimuli has been reported previously [12, 13].

In the early anticipation period (Fig. 6 ①), the amplitude attributed to the collision-simulating stimulus was smaller than those attributed to both controls. That should mean that endogenous brain activity anticipating a collision is distinguished from other anticipations. This specific suppression could be caused by intention to take evasive action. On the other hand, in the late anticipation period (Fig. 6 ②), the amplitude attributed to random control decreased just before the target stimulus (Fig. 5), and then the significant difference from the amplitude attributed to the collision-simulating stimulus disappeared. The random control image is also a kind of excitatory stimulus in which the size of the black indeterminate form and the brightness alternate rapidly. The amplitude of the alpha-band rhythm may be reduced by expectation of the random control image.

In the dark period, i.e., time windows of ③, the same dark stimulus was presented to the subjects regardless of the target stimuli, and the amplitudes therefore represent endogenous brain activity. In fact, no significant difference between conditions was observed. The main effect shown by ANOVA may be caused by remaining effects of exogenous visual stimuli.

As a conclusion, it seems likely that intention to take evasive action suppresses alpha-band rhythm during the entire anticipation period. Additionally, expectation of the target stimuli just before the target stimuli can also suppress the rhythm. It is known that alpha-band rhythm is suppressed by attention [14], and the intention and expectation are therefore considered to be related to attention. Evading collisions requires a quick response. Suppression of the alpha-band rhythm in the anticipation period occurred even in the early stage and was detected by the sensors in the occipital area. These results suggest that the alpha-band source is set under a top-down control just after the cue signal and is maintained until the collision.

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