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Alpha-band Rhythm Modulation under the Condition of Subliminal Face Presentation: MEG Study

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Abstract— **The human brain has two streams to process visual information: a dorsal stream and a ventral stream. Negative potential N170 or its magnetic counterpart M170 is known as the face-specific signal originating from the ventral stream. It is possible to present a visual image unconsciously by using continuous flash suppression (CFS), which is a visual masking technique adopting binocular rivalry. In this work, magnetoencephalograms were recorded during presentation of the three invisible images: face images, which are processed by the ventral stream; tool images, which could be processed by the dorsal stream, and a blank image. Alpha-band activities detected by sensors that are sensitive to M170 were compared. The alpha-band rhythm was suppressed more during presentation of face images than during presentation of the blank image (p=.028). The suppression remained for about 1 s after ending presentations. However, no significant difference was observed between tool and other images. These results suggest that alpha-band rhythm can be modulated also by unconscious visual images.**

I. Introduction

The human brain has two streams to process visual information [1, 2]. The dorsal stream, which arises in the occipital lobe and projects to the posterior parietal cortex, is believed to process spatial location and motion. The ventral stream, which arises in the occipital lobe but projects to the inferotemporal cortex, is thought to process the color and shape of objects and some visual objects such as faces. The region for recognition of faces, name the fusiform face area (FFA), is located in the ventral occipitotemporal cortex [3, 4]. In event-related potential studies, a negative potential named N170 is known as a face-specific signal [5, 6].

Continuous Flash Suppression (CFS), which was introduced by Tsuchiya and Koch [7], is a visual masking technique using binocular rivalry. In CFS, a dynamic random noise is presented to the dominant eye, while a target image is presented to the non-dominant eye. By adjusting the contrast of the target image to a threshold (subliminal) level, the target image can be presented invisibly or unconsciously. Fang and He utilized the CFS technique in an fMRI study and demonstrated that the ventral visual stream is not activated by invisible images. They also suggested that tool images can be processed by the dorsal stream even if they are unconscious. On the other hand, Sterzer et al. measured M170, which is the counterpart of N170 recorded by magnetoencephalography (MEG), and found that invisible face images evoke a weaker M170 than do visible face images; however, invisible face images still evoke a larger M170 than do invisible house images. These results suggest that FFA is activated by face images even if they are invisible. It is known that the alpha-band rhythm can be suppressed not only by physical properties of visual stimuli but also by cognitive brain activity.

We therefore investigated whether the alpha-band rhythm can be modulated by visual stimuli presented unconsciously by the CFS technique. We compared magnetically recorded alpha-band activities modulated by the following three image conditions: face images, which are processed by the FFA; tool images, which are considered to be processed by the dorsal stream, and a blank image.

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II. Methods

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

A. Stimuli

The sequence of the visual stimuli is shown in Figure 1. As target stimuli, five tool pictures and five neutral (non-emotional) face pictures were used. The face pictures were obtained from the DB99 database organized by Advanced Telecommunications Research Institute International in Japan, while the tool pictures were uncopyrighted pictures obtained from the Internet. These images were modified appropriately to have similar physical

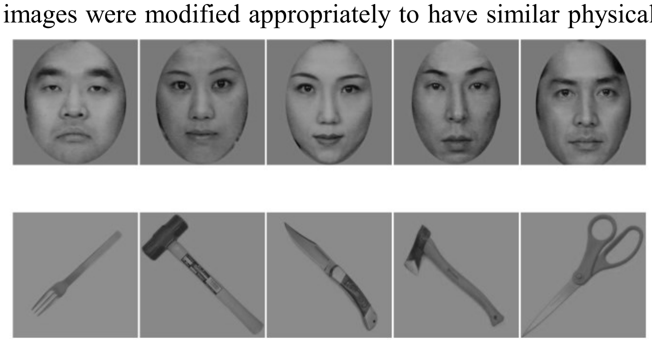

Figure 1. Target visual stimuli. Face images (upper column) and tool images (lower column).

properties (brightness and contrast) between conditions (face/tool/blank) [8, 9].

B. Procedure

Before each recording, the dominant eye of each subject was identified. In the experimental session (Figure. 2), each trial started with the presentation of a fixation cross for 500 ms. Subsequently, 10 Hz dynamic high-contrast random-noise patterns and low-luminance low-contrast target (face/tool/blank) images were presented to the dominant and non-dominant eyes, respectively, for 200 ms. Anaglyphs were used to present different images to the subjects' left and right eyes. Subjects could report the dynamic random noise but not the static target images because the contrast level of the target image was adjusted in advance so as to make conscious perception impossible [9]. After the presentation of the target image unconsciously, a blank image was presented instead of the target image while a dynamic noise still presenting to the dominant eye for 1800 ms. Finally, a question mark was presented during the inter-stimulus interval for 4500－5500 ms. The experiment was divided into three sessions with each session consisting of 40 trials to avoid fatigue. For maintaining the attention of each subject, several oddball trials including a high-contrast target image were presented in each session. Each subject was instructed to press the button with their right index finger when they detected an oddball trial during presentation of the question mark. The stimuli were presented on a back projection screen. The visual angle was adjusted to 7 degrees in both width and height.

C. Recording

MEG signals were recorded with a 76-ch helmet system (Elekta-Neuromag, custom-type) from 8 healthy volunteers (mean age: 23.3 years; standard deviation: 1.9 years, six males and two females). The pass-band was from 1 to 200 Hz, and the signals were sampled at 600 Hz

D. Analysis

First, we merged the MEG signals of the three sessions. We then created a template of transient responses by averaging the MEG signals over epochs and 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 the Hilbert transform. We averaged the obtained envelopes over epochs separately for each target condition (face/tool/blank) excluding the oddball epochs.

The topographies of transient magnetic field responses were also examined. Typical dipolar field patterns were observed around 170 ms after the onset of the "target and noise" image in most subjects. We therefore selected 10 sensors of an individual subject that are sensitive to the 170 ms peaks. The values of root-mean-squares (RMS) of the field strength of the 10 sensors at the peak around 170 ms were statistically analyzed by ANOVA. Envelopes obtained by the Hilbert transform were also averaged over the same 10 sensors. The time-averaged amplitude of the alpha-band rhythm, which was represented by the envelope, within the following three time windows were analyzed by one-way ANOVA followed by Tukey's multiple-comparison tests: ① 0－200 ms during presentation of the target image and dynamic random noise, ② 500 －1000 ms and ③ 1000 － 2000 ms during presentation of the blank and dynamic random noise after the "target and noise" image. In analysis of the amplitude of the alpha-band rhythm, the baseline was set as the time-averaged amplitude between -1000 ms and -500 ms, i.e., 500 ms before the fixation onset. That means we analyzed amplitude suppression from just before the fixation. The level of statistical significance was $p < .05$.

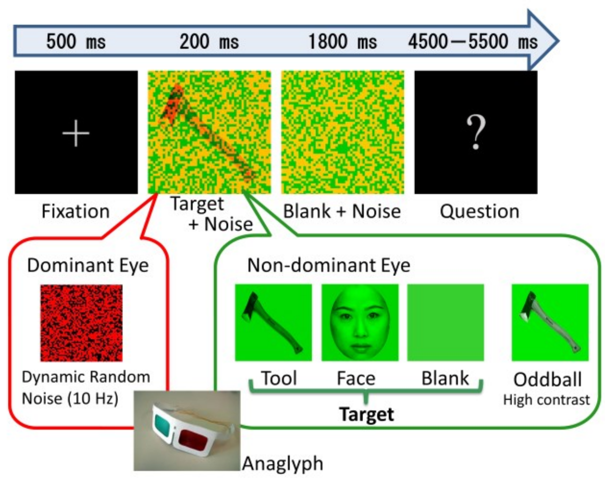

Figure 2. Schematic diagram of one trial. Anaglyphs were used to present monocular images. The target images presented to the non-dominant eye are not perceived consciously because of binocular rivalry

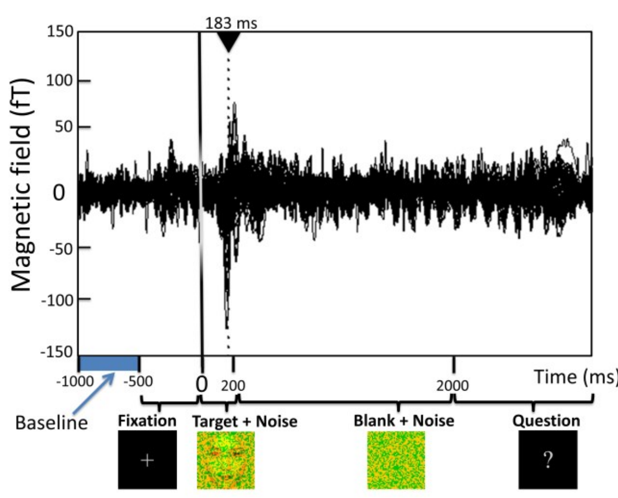

Figure 3. A typical example of transient responses obtained from one subject. All channels filtered with 1－40 Hz are superimposed. 0 indicates onset of the target stimulus.

III. RESULTS

A. Transient response

Figure 3 shows a typical example of transient responses of one subject. Clear peaks are observed after the onset of the "target and noise" image. The topography of the magnetic fields at around 170 ms shows a typical dipolar pattern in which the dipole is located in the occipital area, so they could be considered as M170. The RMS of the field strength extracted from the 10 channels, which are located in occipital area and sensitive to M170, was analyzed by one-way ANOVA. However, no significant difference was observed among the three target conditions ($F(2,14)=.240$ $p=.790$).

B. Time-frequency analysis

Figure 4 shows an example of results of time-frequency analysis by wavelet-transform for another subject. Although we could not find any characteristic pattern, spontaneous rhythms of alpha band (8-13 Hz) were found and they seemed to be modulated by the visual stimuli. Since most of the results of time-frequency analysis showed notable alpha-band activities and their modulation by the visual stimuli, we decided to focus on analysis of alpha-band rhythm.

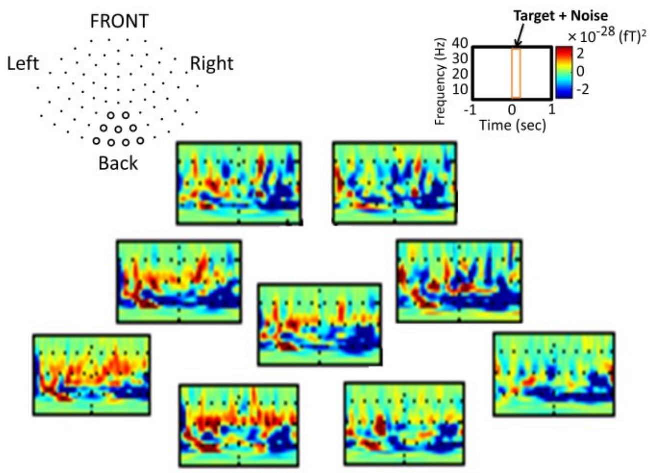

Figure 4. Example of results of time-frequency analysis by wavelet transform. Results of sensors in occipital area are shown.

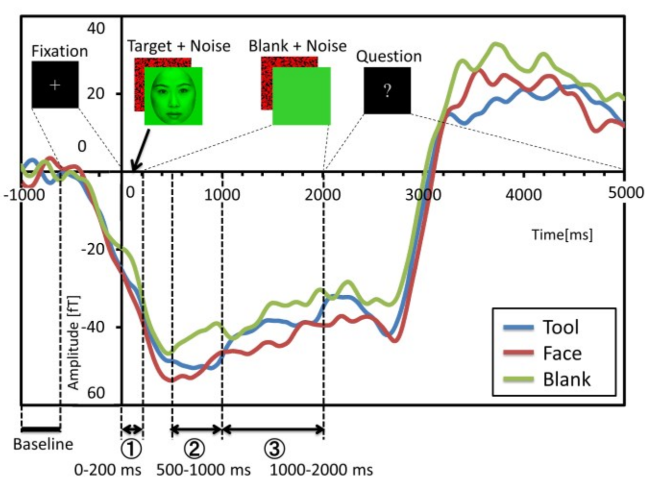

Figure 5. Time courses of amplitude of alpha-band rhythm averaged over 8 subjects. Modulation from the baseline, which is set as the averaged value between -1000 and -500 ms, is shown

C. Amplitude of alpha-band rhythm

The amplitudes of alpha-band rhythm, i.e., envelopes of the rhythm, are shown in Figure 5. The baseline was set as averaged amplitude between -1000 ms and -500 ms, and this figure therefore shows amplitude modulation from the baseline. The amplitudes are clearly suppressed by the fixation and the "target and noise" and recovered gradually during presentation of the "blank and noise". The amplitudes increase dramatically after about 500 ms from the onset of presentation of a question mark image. These amplitudes were calculated by averaging over 10 sensors located in the occipital area, and the results demonstrated that alpha-band rhythm of occipital area can be modulated by visual stimuli.

Amplitude modulations of the alpha-band rhythm were evaluated among the three conditions by one-way ANOVA in the three time windows (Figure. 6). In the time window ① 0 − 200 ms, in which "target and noise" was presented, a significant difference among the conditions ($F(2,14)=4.665$ $p=.028$) appeared. Additionally, by Tukey's multiple-comparison tests, amplitude attributed to the face condition was significantly smaller than that of the blank condition ($p=.022$). A significant difference was also observed in the time window ② 500 − 1000 ms ($F(2,14)=3.758$ $p=.049$) even after ending presentation of the target image. Multiple comparison tests showed that amplitude attributed to the face condition was still significantly smaller than that of the blank condition ($p=.044$).

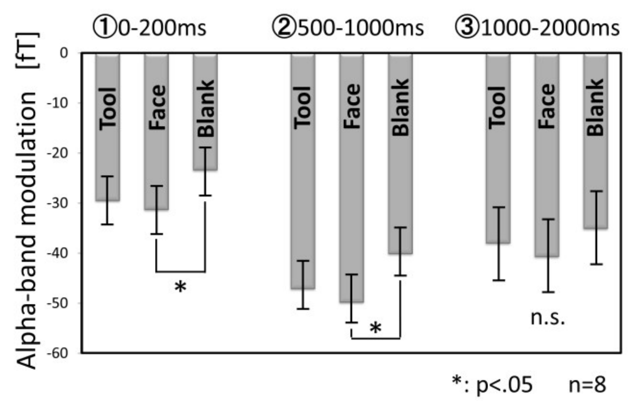

Figure 6. Results of group-level statistical analysis of amplitudes of alpha-band rhythm. Reductions from the baseline (-1000−-500 ms, i.e., 500 ms before fixation onset) to the time windows of ① 0−200 ms (left row: during presentation of the "target and noise"), ② 500−1000 ms and ③ 1000−2000 ms (middle row and right row, respectively: during presentation of "blank and noise"). Alpha-band rhythm is suppressed more by the face images than by the blank images. Moreover, the significant difference seems to remain until about 1 s after the" target and noise" onset.

However, no significant difference was observed in the time window ③ 1000－2000 ms ($F(2,14)=.909$ $p=.426$).

IV. Discussion

It should be noted that the fixation could suppress alpha-band rhythm, although its physical properties (brightness and color) were almost the same as those of the question mark image (Figure 5). This result suggests that the modulation is caused by some endogenous brain activity, probably attention.

The most notable result in this study is that the face image suppressed alpha-band rhythm more than did the blank image despite their perceptual invisibilities. Although no significant difference was observed in field strength at 170 ms (M170) among the conditions, the sensors that should be sensitive to M170 detected significant alpha-band suppression by the face image. This finding is consistent with results obtained by Sterzer et al. [10] showing a significantly greater signal in response to an invisible face image than that in response to an invisible house image at the latency and source location of M170. This significant difference between the face and blank images seems to be maintained for about 1 s after the "target and noise" onset (Figure. 5), indicating that processing of the face image is prolonged for about 1 s.

On the other hand, no significant difference was observed between alpha-band modulation attributed to the tool and those of others. A simple interpretation of this result is that the sensors sensitive to M170 were insensitive to alpha-band modulation by tools, resulting in lower signal-to-noise ratio for tools. Another possibility, however, is that face and tool images are processed differently under an unconscious condition. That is, while it is generally accepted that visible face and tool information would concurrently run through V1 in the occipital area, invisible face and tool information may pass through a different route before reaching V1. This interpretation does not conflict with the suggestion by Fang et al. [11] that a tool image can project directly from the lateral geniculate nucleus (LGN) to the middle temporal area or V5. Thus, it is possible that invisible face and tool images pass through different subcortical pathways from the LGN. Source estimation of rhythm modulation, by the beamformer method [12, 13] for instance, should be performed in the near future to clarify the rigid activation area or the pathways.

In conclusion, our results demonstrate that an invisible face image also suppresses alpha-band rhythm in the occipital area probably originating in the vicinity of the M170 source. Additionally, no significant difference between the alpha-band rhythm suppressed by the tool images and that suppressed by the face images may be collateral evidence that tool images are processed by different subcortical pathways. Comparisons of cognitive processes, especially those under an unconscious condition, between different emotional face images (such as happy and sad faces) and between genders of subjects remain as topics of future studies.

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