A study on perceptual processing of teeth images with occluded areas based on the analysis of event-related potential

（歯の遮蔽像の知覚処理に関する事象関連電位による研究）

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A study on perceptual processing of teeth images with occluded areas based on the analysis of event-related potential

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Key word

incomplete tooth images, amodal completion, event-related potential, equipotential map, first molar

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Abstract

Based on visually obtained information such as a spatial arrangement of teeth and tooth shape, dentists can distinguish the tooth type by extracting and collating dental features. They can perform tooth identification regardless of whether the presented tooth images are complete or incomplete. The aim of this study was to clarify the cognitive information processing of tooth images with occluded area.

The subjects were 11 fifth-year dental students with both dental knowledge and experience of clinical training (average age 23.8 years). The complete tooth images or incomplete tooth images (with occluded areas) were presented according to certain conditions, and an electroencephalogram analysis was performed focusing on event related potential.

The P300 is an evoked potential that occurs 300 ms after an event and is composed of P3a and P3b. They are thought to be the stage for information processing after receiving visual information. In our study, the results of P3a showed that the occipital and temporal regions adjacent to the ventral pathway were more active in incomplete image processing than complete image processing but that the activity decreased in the parietal region. In P3b, the activity of the parietal region close to the dorsal pathway was higher, but the activity of the temporal region was lower. It was concluded that the visual complement was done for the recognition of the occluded tooth images.

Introduction

Dentists conduct medical interviews and examinations to obtain patient information. Thereafter, they collate the most probable disease based on their vast knowledge of diseases and diagnose and identify the disease. It has been reported that there are several ways of thinking about the diagnosis made by dentists [1]. Competent dentists have several patterns when making a diagnosis and use the patterns frequently in daily clinical practice to make an efficient diagnosis. To elucidate the way of thinking by pattern recognition, we thought it necessary to clarify the nature and mechanism of cognitive process. In previous studies in our laboratory, the cognitive process had been examined using electroencephalogram analysis [2-4]. One method of brain wave measurement uses event-related potentials (ERP). This method measures potentials that are evoked by the presented sensory stimuli and appear after a certain processing time in the cerebrum. ERP is an intrinsic potential that reflects a cognitive response to a stimulus. In previous studies, ERP has been used to elucidate higher brain functions [5, 6] and has been widely applied in the medical field [7, 8].

There are various situations where dentists need to distinguish the tooth type in clinical practice, for example when the target teeth are covered with soft tissues such as gingiva or buccal mucosa. In some cases, a substantial part of a tooth might be missing due to dental caries, attrition or abrasion. Dentists perform feature type discrimination after extracting and collating features in their brain based on information such as spatial arrangement and tooth shape obtained visually. Thus, dentists are able to perform dental classification regardless of whether the shape is complete or incomplete.

There are two types of visual complementation in recognition of occluded areas: amodal completion and modal completion. Modal completion is visual recognition that allows one to subjectively perceive nonexistent things as they really exist. Amodal completion is visual recognition in which the occluded part is complemented in the brain to recognize the whole image. Dentists use their knowledge of the shapes of teeth and amodal completion when presented with incomplete tooth images [9, 10]. However, when they distinguish the tooth type using complete and incomplete tooth images, there are many unclear points about how information processing is performed. The aim of this study was to clarify the cognitive information processing of tooth images with occluded areas using ERP.

Materials and Methods

The subjects were 11 fifth-year dental students (average age 23.8 years) with both dental knowledge and experiences of clinical training (School of Dentistry at Matsudo, Nihon University, Chiba, Japan). The curriculum in our facility follows a standard curriculum of a Japanese dental college. Students study with emphasis on tooth morphology and its relationship to normal physiologic function by the second year. The students have basic dental clinical knowledge and practical training in the third and fourth years. Fifth-year dental students continue to treat patients under faculty supervision, working toward achieving a certain level of clinical experience at the university hospital.

All subjects were healthy, had visual acuity that did not interfere with the right-handed experiment, and had no history of mental illness. As measurement conditions, we had each subject sit on a chair in a resting state in an electromagnetically shielded room and affixed the subject's head on a chin rest. Then the subject was presented with a sample on a monitor located 50 cm in front of him/her. The conditions for electroencephalogram (EEG) measurement are shown in Fig. 1.

The sampling frequency of EEG was 1,000 Hz. Electrode mounting was set based on the International 10-20 method [11]. We placed the electrodes at 21 sites on the scalp with the subject's earlobes as references. We recorded the derived data using a digital electroencephalograph (Nicolet One®; Gadelius Medical, Tokyo, Japan). The contact impedance was set to 10 KΩ or less. We set the low frequency filter to 0.1 Hz and the high frequency filter to 100 Hz. Images were presented one at a time randomly following the oddball paradigm using a multi-trigger system (Multi-Trigger System®; Medical Try System, Tokyo, Japan).

The presentation time for each image was 1500 ms, and 300 presentations (tasks) were performed per assignment. The target stimulus and non-target stimuli were presented in a ratio of 2:8. Subjects were instructed to press the specified button only on observation of the target stimulus and were unable to observe their own hands directly. The objective of the task was to distinguish the tooth type using pictures of the complete tooth images (hereinafter referred to as “control”) and the occluded tooth images (hereinafter referred to as “amodal”). Each assignment took about 15 minutes and was performed with a 5minute break between assignments in consideration of the subject’s fatigue.

The task was to identify teeth using a sample of the tooth image from the cusp side each image (image size, 480×480 pixels) was presented on a monitor. The task was performed using images with the buccal side upward because most textbooks of dental anatomy present tooth images in this orientation. The sample was created with a white tooth occlusal surface on a black background. We also put a white dot near the buccal side of the tooth. The reason for this setup is to prevent recognition of teeth based on regularity of the shape as the subjects gazed on only one point in the visual field at the time of discrimination. In other words, there was a degree of freedom in terms of shape when the subject performed discrimination.

Control (complete tooth images)

The target stimulus was a mandibular right first molar sample. Non-target stimuli were samples of the mandibular left first molar, maxillary right first molar, and maxillary left first molar (Fig. 2).

Amodal (incomplete tooth images)

Mandibular molars have many anatomical features in the mesial region. Therefore, we created a specimen that left out the distal view in the occlusion images. The target stimulus was a mandibular right first molar sample. Non-target stimuli were samples of the mandibular left first molar, maxillary right first molar, and maxillary left first molar (Fig. 3).

We recorded the correct answer rate and the reaction time from the presentation at the task execution to the button press. The EEG signal elicited by the target stimulus was recorded on a digital electroencephalograph. Then we extracted ERP from the recorded electroencephalogram (EEG) data. We obtained the waveform from the extracted ERP using the EEG data analysis software EPLYZER® (Kissei Comtec, Nagano, Japan). We analyzed the waveform measured for the target stimulus.

We also identified the waveform components (N100, MMN, N2b, P3a, and P3b) in the grand average waveform. The time immediately after the stimulation was defined as 0 ms. We determined the peak value within each latency, and the time to the peak value was defined as the latency of each waveform component and the potential of the peak value as the amplitude. The waveform component whose latency appeared at 0-90 ms was defined as N100, at 91-150 ms as MMN, at 151-240 ms as N2b, at 241-450 ms as P3a, and at 451 -600 ms as P3b.

We created an equipotential map using ATAMAP II® (Kissei Comtech, Nagano, Japan) for the amplitude values of each waveform component at 21 sites on the scalp. We compared the activity states from the obtained results and examined the difference in the processes of information processing. Statistical analyses were performed using statistical software (SPSS Statistics version 21; IBM SPSS Japan, Tokyo, Japan). We examined the correct answer rate, latency, and amplitude from the control and amodal tasks. The examination showed significant differences using a paired t-test. This study was performed with the approval of the ethics committee at our dental school (Approval # EC16-15-11-010-2). The experiment was described in advance to the subjects and performed only after written informed consent was obtained.

Results

1. Correct Answer Rate and Reaction Time

The mean correct answer rate was 98.7±0.7% for the control task and 96.3±0.9% for the amodal task. The mean reaction time was 588.7±102.5 ms for the control task and 664.2±161.5 ms for the amodal task. There was no significant difference in the mean correct answer rate or reaction time (Table 1).

2. Latency of Each Waveform Component

The control task reaction time was 46.2±9.9 ms for N100, 128.0±12.0 ms for MNN, and 162.0±2.8 ms for N2b. The amodal task reaction time was 56.2±13.1 ms for N100, 135.3±14.7 ms for MNN, and 164.4±3.4 ms for N2b. The reaction time did not differ significantly between the control and amodal tasks for N100, MMN and N2b (Table 2).

The control task reaction time was 315.1±27.3 ms for P3a and 480.2±16.3 ms for P3b. The amodal task reaction time was 343.1±18.5 ms for P3a and 546.5±16.7 ms for P3b. The reaction time significantly differed for P3a and P3b. The latencies were longer for the amodal task than the control task (Table 2).

3. Comparison of waveform components

1) Comparison of N100

The N100 showed activity from the occipital region to the temporal region for both the control and amodal tasks. The frontal area was found to be less active in both the control and amodal tasks. All electrodes on the equipotential map with N100 showed similar patterns the control and amodal tasks (Fig. 4).

2) Comparison of MMN

For MMN, there was activity from the occiput to the temporal region in both tasks. MMN showed greater activity in the occipital and temporal regions than N100. All electrodes on the equipotential map with MMN showed similar patterns the control and amodal tasks (Fig. 4).

3) Comparison of N2b

The N2b showed occipital and temporal activity in both the control and amodal tasks (Fig. 5). At Pz, the value was 3.4 ± 1.4 μV for the control task and 1.7 ± 2.8 μV for the amodal task. There was a significant difference between the control and amodal tasks (Table 3).

4) Comparison of P3a

In the control P3a, there was wide activity from the occiput to the parietal region. In the amodal P3a, there was activity from the occipital to temporal regions but the activity in the parietal region was low (Fig. 5). The value was 3.2±1.6 μV for the control task at Cz and 5.8±1. 0 μV at Pz. It was 0.2±1.7 μV for the amodal task at Cz and 1.4±1.8 μV at Pz. For both Cz and Pz, there was a significant difference between the control and amodal tasks. There was a significant difference between the amodal task and the control task (Table 4).

5) Comparison of P3b

For P3b, there was a strong activity from the occipital region to the parietal region in the control task, and the temporal region was also active. In the amodal task, the activity was found mainly in the parietal region and not much in other regions (Fig. 5). For the control task, it was 7.0±1.7 μV for C3, 8.4±3.6 μV for P4, 6.4±2.5 μV for T4, and 7.3±4. 2 μV for T5. For the amodal task, it was 3.1±2.0 μV for C3, 1.7±2.5 μV for P4, 0.0±2.3 μV for T4, and -0.9±2.3 μV for T5. For all C3, P4, T4, and T5, there was a significant difference between the control and amodal tasks. There was a significant difference between the amodal task and the control task (Table 5).

Discussion

When humans perform information processing, they extract characteristic parameters of the presented object from a large amount of information. They make final judgments through various cognitive activities by collating these characteristic parameters with the knowledge accumulated. The subjects of this study were fifth-year dental students. They had taken dental anatomy in lower-division classes and had knowledge of teeth. At the time of the study, they were in clinical training with patients in hospitals, where they observed and learned about teeth from various perspectives. They also had the opportunity to see teeth with dental caries and attrition. Therefore, we tried a cognitive psychological experiment on these subjects to examine the component analysis of ERP and the equipotential map for cognition of incomplete teeth with partially occluded areas. The task difficulty was examined using the correct answer rate and reaction time. The process of cognitive information processing was examined using ERP.

1. Psychological Approach

The topic of this study is the discrimination of tooth image from cusp side. The controls were presented in drawings of teeth with the buccal side facing up, which is the orientation often used in textbooks. Since textbook patterns are formed as formal knowledge based on learning results, this orientation allows easy pattern matching.

In this study, the amodal task consisted of two elements, the visible part and the invisible part. A person not only receives visual information passively, but also performs active information processing based on spatial attention. In the shape recognition of visual information, one can recognize occluded images by complementation, even if an object is partly occluded and not clearly represented. A previous report has found responses related to occlusion completion occurring in the primary visual cortex [12]. In such a situation, a preattentive process is known to occur in which comparison is unconsciously performed relative to the surroundings, and it does not require intentional visual attention and is automated by experience. In this way, one senses a portion that is missing and performs visual completion of an object. It is called “amodal completion” when one perceives the presence of continuous lines and edges that are not actually perceivable [13].

In our study, the control and amodal tasks had no significant difference in the mean reaction times. The mean percentage of correct answers was higher than 96% for both the control and amodal tasks, and the difference was not significant. These results suggest that humans are performing visual complementation when processing in the amodal task. The results of the correct answer rate revealed that it was difficult to examine the difference in information processing between the control and amodal tasks.

2. Neuroscientific Approach

Visual information received from retinal photoreceptors is transmitted from the lateral geniculate nucleus to the primary visual cortex of the occipital lobe of the cerebral cortex. Information is distributed to different areas for each attribute such as position and shape. In addition, information processing is carried out while analysis and addition of information are received in each region. The final information is integrated into visual perception. Visual information processing in the human cerebrum is roughly divided into the ventral pathway and the dorsal pathway.

The ventral pathway is the path of the visual information that reached the primary visual cortex and flows toward the temporal lobe. The ventral pathway has been reported to play an important role in recognizing what the shape of the object is, and when the shape is not clear due to surrounding conditions or when viewed from an unfamiliar angle [14].

The dorsal pathway is a path from the primary visual cortex to the parietal lobe. This the dorsal pathway serves to direct one’s attention to the position and shape of the object and to enable detailed visual recognition [15]. It has been reported that the parietal lobe, which receives information from the primary visual cortex via the dorsal pathway, plays an important role as a site where the shape and size of an external object are recognized from information obtained visually [16,17].

An ERP is induced by psychological activities such as cognition, discrimination, and problem solving, so it is a powerful indicator of cognitive information processing and is often used for research. The advantage of ERP is that it can record the subject's cognitive processes in parallel without distortion, and that multiple measures are available along the time axis [18]. There are several stages in the process of cognitive processing, and characteristic waveform components appear at specific latencies. The purpose of this study was to investigate the characteristics of ERP waveform components in cognitive information processing of occluded tooth images. We made an equipotential map of the whole head and compared N100, MMN, N2b, P3a, and P3b at each electrode.

The N100 has been reported to reflect selective attention to issues [19]. It has been reported that MMN is reflected in a target task that is induced in the vicinity of 100 ms with a simple task after stimulus presentation and occurs especially in the process of easy pattern matching [20]. N100 and MMN are components that appear early in the evoked potential. In the MMN stage, it was speculated that the information processing activity in the temporal region was high in order to access one’s own memory and the primary visual cortex centered on the occipital region.

The N2b is considered as a waveform component of advanced pattern matching process related to the intentional processing of stimulation. N2b has been reported to be a negative waveform associated with the processing of the stimulus that appears when attention and readiness are required during task performance [21].

In our study, N2b latency was not significantly different between the control and amodal tasks. However, the equipotential map showed occipital and temporal activity in both the control and amodal tasks. In N2b, when the subjects classified the teeth, they performed visual information processing while paying attention to the spatial positional relationship and the characteristic shape of the teeth. There was a smaller visual range in the amodal task than the control task. Therefore, it was speculated that the activity of the temporal region was higher in the amodal task than the control task because the subjects frequently accessed their memory and that advanced matching processing in Pz was not carried out.

The P300 is the intrinsic evoked potential that appears with a maximum positive amplitude of about 300 ms after the event, and P300 is composed of two lower components, P3a and P3b [22,23]. P3a and P3b are late evoked potentials. It has been reported that the relationship between late evoked potentials and the evaluation of cognitive ability is useful. Evoked potential P3a appears early, almost constantly appears in response to sensory stimuli, and does not differ by intellectual ability. Therefore, P3a is said to indicate the process of orientation of attention [24]. In this process, the parietal lobe is reported to be the region of neural activity where the information is processed [25].

The P3b is said to be involved in the termination of cognitive encoding processing or updating working memory [26]. Visual information processing involves a mechanism for flexible information processing from all angles in space and time. The recognized information is projected to the temporal lobe through the ventral pathway, which is an information processing pathway. The frontal region is said to fulfill the role in which it actively retains information from past memory for use in problem solving [27].

In our study, P3a for the control task showed higher activity in the parietal region than that for the amodal task, and the two tasks showed a significant difference at Cz and Pz. In the control task, the subjects could have easily compared the previously learned features of teeth with the features in line drawings of teeth in the presented samples. That is to say, the subjects' explicit knowledge based on textbook patterns was gained as a result of learning up to that point. As a result, the subjects were able to recognize the shape and size from the information obtained by the visual perception of the outside world.

In the amodal task, some tooth features were not completely visible. The activity of the temporal region adjacent to the ventral pathway was speculated to be high. Because the subjects could distinguish the tooth type by based on the amodal completion of the occluded area by accessing their memory.

The P3b stage is where the information processed from visual perception is compared and verified internally. In the control task, the subjects completed the recognition of the visual image using various experiences as knowledge. After recognizing the visual information, they made recognition judgment by collating information against information in their memory when differentiating teeth. In the amodal task, a limited amount of information was obtained because the range of visual perception was narrower than that in the control task. In this study, P3b was the result of the activity of the occipital region, parietal region, and temporal region for the complete tooth images, and the subjects made judgments as they examined the information while collating it with that in their memory. The information processing activity was indicated to be high in both dorsal and ventral pathways.

In the amodal task, the parietal region was active. Since there was limited information presented in the amodal task, the information processing activity was high only in the dorsal pathway without access to the temporal region. However, information processing on the ventral pathway could not be performed efficiently. This fact indicates that the information processing by higher spatial recognition is necessary when the information processing of the occluded tooth images is carried out.

Our study clarified the following on the differentiation of occluded tooth images. The results of N2b showed that the subjects had difficulty efficiently distinguishing the tooth type and they frequently accessed their memory. Since the occluded tooth images had a small visible range, it was assumed that, as shown in P3a, the subjects distinguished the tooth types by activating the function of the temporal region adjacent to the ventral pathway and performed amodal completion . Although only the information processing activity of the dorsal pathway was actively carried out in P3b, it was indicated that the information processing by higher spatial recognition was necessary, since the information processing of the ventral pathway could not be efficiently carried out. We have concluded the following from our study of occluded tooth images using an equipotential map representing changes of ERP. Information processing in the amodal task was carried out by the mutual communication including the dorsal pathway and ventral pathway of the brain, and then high-order function processing was carried out. It was also indicated that information processing occurred by the recognition of the occluded tooth images through amodal completion. In addition, it was suggested that the recognition in the amodal task was performed with visual complementation.

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Table and Figure

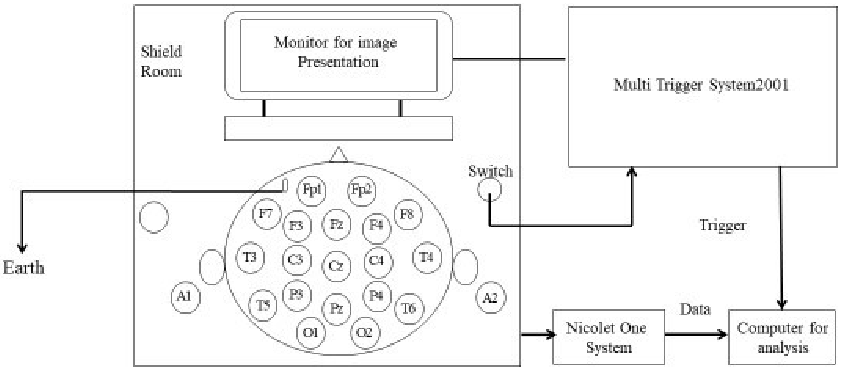


Fig. 1. Conditions for electroencephalogram measurement with illustration of electrodes positioned at 21 sites on the head according to the International 10-20 method.

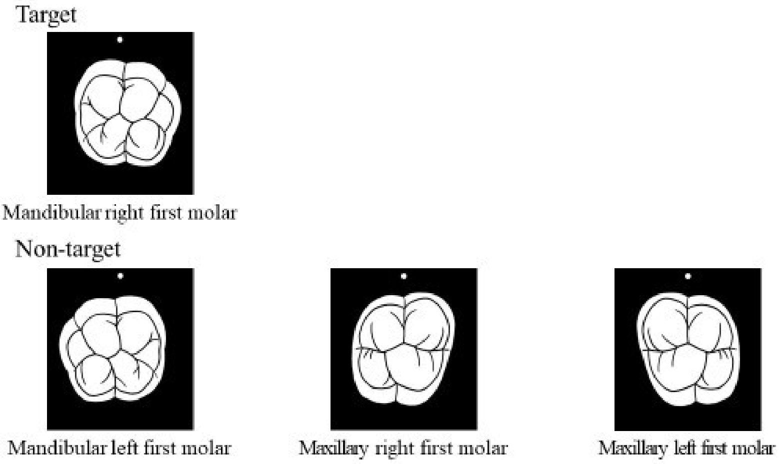
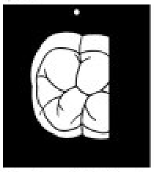


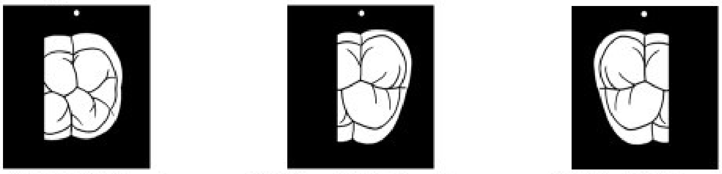
Fig. 2. Control (complete tooth images)

Target



Mandibular right first molar

Non-target



Mandibular left first molar Maxillary right first molar Maxillary left first molar

Fig. 3. Amodal (incomplete tooth images)

Table 1. Correct answer rate and reaction time

	Correct answer rate (%)	Reaction time (ms)
Control	98.7 (0.7)	588.7 (102.5)
Amodal	96.3 (0.9)	664.2 (161.5)

n=11, Mean (SD)

The correct answer rates were compared by the χ^2 test but showed no significant difference. The reaction times were compared by the t-test but showed no significant difference.

Table 2. Latency of each waveform component

(ms)	N100	MMN	N2b	P3a	P3b
Control	46.2 (9.9)	128.0 (12.0)	162.0 (2.8)	315.1 (27.3)	480.2 (16.3)
				*	**
Amodal	56.2 (13.1)	135.3 (14.7)	164.4 (3.4)	343.1 (18.5)	546.5 (16.7)

n=11, Mean (SD) paired t-test $*p<0.05$ $**p<0.01$

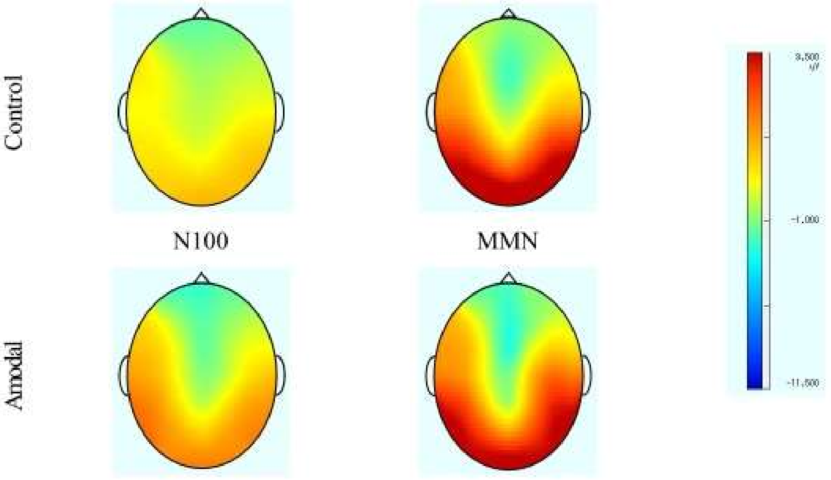


Fig. 4. Equipotential map of each waveform component (N100 and MMN)

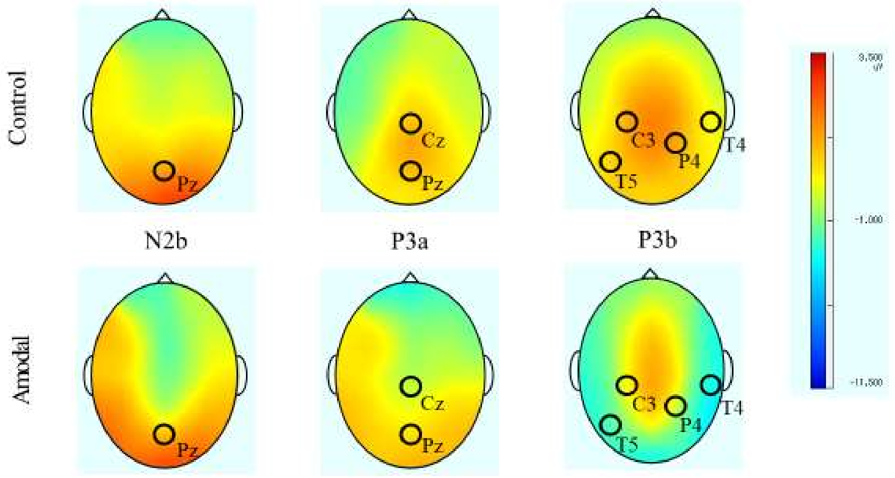


Fig. 5. Equipotential map of each waveform component (N2b, P3a, and P3b)
Points showing significant differences in 21 equipotential maps indicate indicia.

Table 3. Comparison of N2b

(µV)	Pz	
Control	3.4 (1.4)	*
Amodal	1.7 (2.8)	

n=11, Mean (SD) paired t-test * $p < 0.01$

Table 4. Comparison of P3a

(μV)	Cz	Pz
Control	3.2 (1.6)	5.8 (1.0)
	*	*
Amodal	0.2 (1.7)	1.4 (1.8)

n=11, Mean (SD) paired t-test * $p < 0.01$

Table 5. Comparison of P3b

(μV)	C3	P4	T4	T5
Control	7.0 (1.7)	8.4 (3.6)	6.4 (2.5)	7.3 (4.2)
	*	*	*	*
Amodal	3.1 (2.0)	1.7 (2.5)	0.0 (2.3)	-0.9 (2.3)

n=11, Mean (SD) paired t-test * $p < 0.01$