

# Investigating the face pareidolia neural mechanism

(顔パレイドリア現象の神経機序の解明)

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## Abstract (Doctor)

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Approx. 800 words

Humans have an excellent ability to face perception. For example, even a casual pattern such as a cloud may appear like a face. The phenomenon that is seeing objects as a face is called "pareidolia." However, the details of the mechanism of this phenomenon have not been clarified. The purpose of this thesis is to clarify the representation in the brain involved in the face pareidolia phenomenon, which is an illusion of face perception, by psychological, electroencephalogram (EEG), and pupil diameter measurements. In particular, we focus on the differences in the brain and behavior before and after the face pareidolia phenomenon.

First, we investigated whether the inversion effect index of the N170 component reflected face-likeness by observing the correlation between the event-related potential (ERP) components and behavioral reports of face-likeness. Previous ERP studies showed that the P1 component (early visual processing), the N170 component (face detection), and the N250 component (personal detection) reflect the neural processing of faces. Inverted faces were reported to enhance the amplitude and delay the latency of P1 and N170. To investigate face-likeness processing in the brain, we explored the face-related components of the ERP through a face-like evaluation task using natural faces, cars, insects, and Arcimboldo paintings presented upright or inverted. We found a significant correlation between the inversion effect index and face-like scores in P1 in both hemispheres and N170 in the right hemisphere. These results suggest that the judgment of face-likeness occurs in a relatively early stage of face processing.

Next, we investigated how both aspects of bottom-up processing and top-down modulation contribute to face-likeness perception. Humans can immediately judge what kind of object it is by looking at the object. Especially for the face, the ability is sharpened. This ability to quickly group experienced stimuli into meaningful categories (perceptual categorization) is undoubtedly one of the most fundamental high-level brain functions. In the visual domain, the method of investigating the perceptual categorization process is to combine visual periodicity with a direct recording of neural activity, for instance, using EEG. We considered this category-selective response might be generated or modulated by face-likeness. We recorded EEG while presenting natural images of objects at a fast-periodic rate of 12 Hz. We compared neurophysiological responses to periodic and non-periodic face and face-like object stimuli in a fast-visual stream. Moreover, we presented an inverted face and face-like object stimuli as a control. As a result, category (face-like object)-selective EEG responses did not elicit in a fast-periodic stream. This result indicates that the face-like category does not generate a unique category-selective response unconsciously. This result suggested that the pareidolia phenomenon does not occur in the bottom-up process.

Moreover, we investigated face pareidolia using pupillary response. The pupillary response was suggested to be influenced by high-level cognition. Therefore, we predicted that the change of pupil diameter might be induced by face pareidolia. We measured that pupil diameter when stimuli were perceived as faces. The stimuli consisted of five circles, including a big circle and four small circles. The subjects performed two tasks (face-like and symmetry) to the same stimuli in the block design. As a result, pupil dilation in face-like conditions showed differences between the face-like task and symmetry task. However, pupil dilation in the symmetry condition showed no differences between tasks. These results suggest that this pupillary effect is specific for the face-like processing by the top-down process and not specific for the symmetry processing.

Lastly, we clarified preference changes with the pareidolia phenomenon. We hypothesized that a face-like object elicited an orienting response, like a face, and attracted more attention than other visual stimuli. However, it is predicted from past studies that the effect does not affect unless a face-like object is recognized as a face. We investigated whether seeing objects as a face would influence preference. In the experiment, we used a pareidolic image that could be perceived as a face or abstracts painting. These images are presented upright or inverted. The participants performed two tasks. 1) to select more preferred in the two alternatives forced-choice task. 2) face-like evaluation tasks. We divided the participants into two groups in the order in which the tasks were performed. The group that first performed "Face-likeness evaluation task," and then performed "Preference task" was defined as "Face biased group." Another group named "No face biased group" performed the first "Preference task" and then "Face-likeness evaluation task." As a result, the Face biased group preferred the upright than the inverted images, although another group did not prefer the upright images. This result suggested that the pareidolia phenomenon affects preference.

We clarified the differences in the brain and behavior before and after the face pareidolia phenomenon. Besides, we identified timing, area, and pupil response associated pareidolia phenomenon. In the future, the findings of the study might be of use to person-to-machine communication or social life.



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# Chapter 1

## Introduction

The purpose of this thesis is to clarify the representation in the brain involved in the face pareidolia phenomenon, which is an illusion of face perception, by psychological assessment, electroencephalogram (EEG), and pupil diameter measurements. In particular, we focus on the difficult in the brain and behavior between before and after the face pareidolia phenomenon. Movies and beautiful scenes made with high elaborate CG look real; however, the human face made with sophisticated CG feels unnatural. Human face perception is special, and it can process detailed information compared with other object perception. Such high face perception ability is prominent in the perceptual aspect and the cognitive/memory aspect.

Nevertheless, this high face perception ability also affects objects. For example, the Arcimboldo painting shown in Figure 1.1 has a face composed of objects other than the face, such as vegetables, fruits, and chicken. It is difficult to find a face when the painting is upside down, but it is easy to find a face when the painting is upright. The face is easily identified if the face is found in an upright orientation, but it is difficult to be identified if it is found in an upside-down orientation. If the face is found even once, it will stand out, and it will be difficult to pay attention to objects other than the face. The findings show that our behavior for this painting has changed after finding the face.



Figure 1.1: The Arcimboldo paintings.

## 1.1 Face perception

Faces are the most important visual stimuli for social communication. The face is in itself just one of the visual objects; however, it has a socially important meaning and conveys various information. For example, when humans see each other's faces, personal information can be read immediately, and emotions can be understood from facial expression and color. The most popular form of animal communication is the revealing of characteristic body parts and natural movements. For humans, this information is gathered in the face. Accordingly, face perception becomes a specialized ability for humans because of the existence of specialized brain areas, which are specific to the face and the innate properties of face perception. Fantz et al. identified the innate properties of face perception [1] [2] [3] [4], and thereafter, the innateness of face perception has been studied extensively. Goren et al. compared the face arrangement condition, the face shape without facial pattern condition, and the correct facial pattern condition in infants' study, and they showed that infants preferred the correct facial pattern condition [5]. Simion et al. suggested that newborns preferred "top-heavy" stimuli, and such bias may account for neonatal face preference [6]; the findings indicate that "top-heavy" arrangements (which gather information at the top), rather than the specific parts such as eyes, nose, and mouth, are essential. The pattern of "top-heavy," which shows preference even for newborns, is the basis of face perception.

### 1.1.1 Face detection and its mechanism

As described above, the face is an extraordinary visual stimulus for humans. It is just one of the visual objects, but it has socially important meanings and conveys various information such as personal identification, facial expressions, and age. In order to recognize a face, it is necessary to

perceive the whole face rather than identify each facial part separately. The process to perceive this whole face is classified as “configural processing” / “holistic processing.” “Featural processing,” a process opposite to this whole process, conducts to perceive individual parts. Configural processing has two stages: the first-order and second-order processes. According to Maurer et al., the first-order process is to perform face detection, and the second-order process is to distinguish the small difference in face arrangement and perform face discrimination.

The first-order and second-order processes of configural processing are described in detail as follows. The first-order process is to detect the face from the correct arrangement of eyes, nose, and mouth, and this function is sensitive for newborns [5]. Most importantly, in this first-order process, the elements used for face detection are face arrangement rather than eyes, nose, and mouth features. The pareidolia phenomenon described in the following sections is considered to be caused by face detection in this first-order process. The second-order process is to distinguish individual faces based on subtle differences in the arrangement of eyes, nose, and mouth on each face. Thus, personal identification is possible even if the hairstyle changes.

### 1.1.2 Face perception model

Bruce & Young(1986) proposed a functional model for the processing of various information obtained from faces (Figure 1.2) [7]. This model is a relatively old functional model for face perception, and its validity has been discussed in several studies. However, it is still widely cited as a model for the basic processing of face perception.

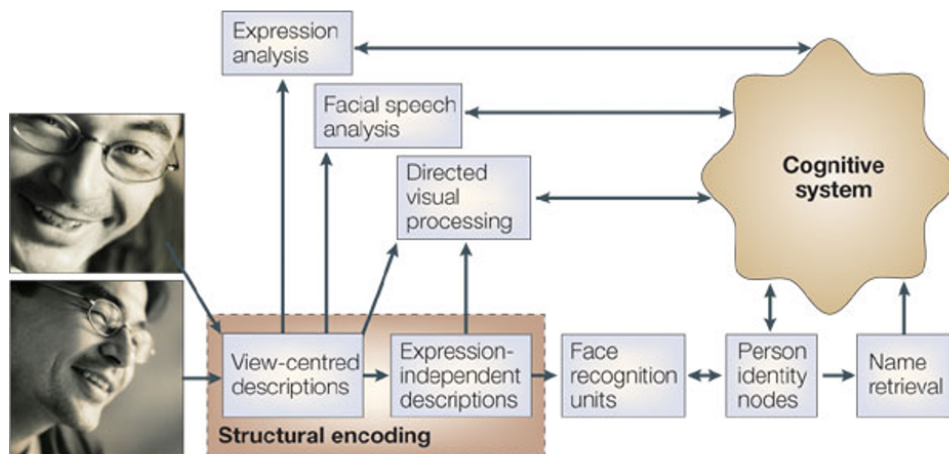


Figure 1.2: Functional model for face recognition proposed by Bruce & Young(1986)[7](Calder & Young(2005) [8]).

This model assumes that a continuous processing path is followed until the name is finally searched after the face is perceived, and the processing is classified into the following four steps.

1. Encoring of visual information: allowing invariant structural properties of the face to be perceived independently of variations in orientation, expression, and context.
2. Face recognition units: comparison of this perceptual information with memory representations of previously seen faces.
3. Person identity nodes: associating these representations with identity specific semantic information about known individuals.
4. Name generation

First, when a face is perceived, visual processing based on image analysis is performed. In addition to this analysis of information used for facial expression recognition and speech recognition, the “expression-independent description” used to identify an individual is performed. It is important that the face can be recognized as a person even if the expression and face orientation change with age and situation. It is considered that the “expression-independent description” formed through the structural encoding hypothesis supports this cognitive behavior. In the face recognition unit process, the perceived information is compared with the memory representation of the face. It is assumed that the description formed in the previous structural encoding process is stored in the face recognition unit. The judgment for known faces is conducted by determining the similarity between the stored information and the perceived information. Subsequently, the process can access “the person identity node,” stored information for identifying an individual. Finally, the person is identified via the name generation.

In addition, the Bruce & Young [7] model has been validated by the neuropsychological model developed by Haxby et al. [9]. They proposed a hierarchical model that is divided into a core system and an extended system. The core system is composed of occipitotemporal regions in the extrastriate visual cortex that mediates the visual analysis of faces. The extended system comprises of regions from neural systems related to other cognitive functions.

They proposed that two classes of face perception operations are kept distinct within the core system. One is a class that captures the “invariant features” for identification, and the other is a class that captures the “changeable features,” such as expression and eye gaze changes. The latter processing class is activated even if the invariant information is activated by changeable information of the face. The brain regions responsible for both systems are

described in Figure 1.3. First, the outline and the edges of the face are encoded in the inferior occipital gyri; the individual information is integrated, while the “invariant information” is integrated into both the lateral fusiform and superior temporal sulcal region. The “changeable information” is input to the superior temporal sulcus and is then processed. The functions of these regions correspond to the structural coding process in Bruce & Young’s face recognition model [7]. With this function, morphological features of faces and expressions are encoded, and appropriate representations are generated so that the extended system can process them. Moreover, DeGelder et al. proposed the subcortical system in addition to the core system and the extended system [10]. In this system, facial information from the retina is transmitted to both the superior colliculus and the amygdala via the thalamus, and this process has been termed as an automatic processing route. It is mainly considered to be a function that relies on low spatial frequency information to detect a face and direct visual attention to the face [11]. Therefore, it is called the unconscious reaction to the face and is to adjust to the subsequent cortical pathway processing. Thus, in addition to the conventional face recognition models, the mechanism of facial recognition processing is gradually being clarified by neuroscientific evidence obtained by the recently developed brain activity measurement technology.

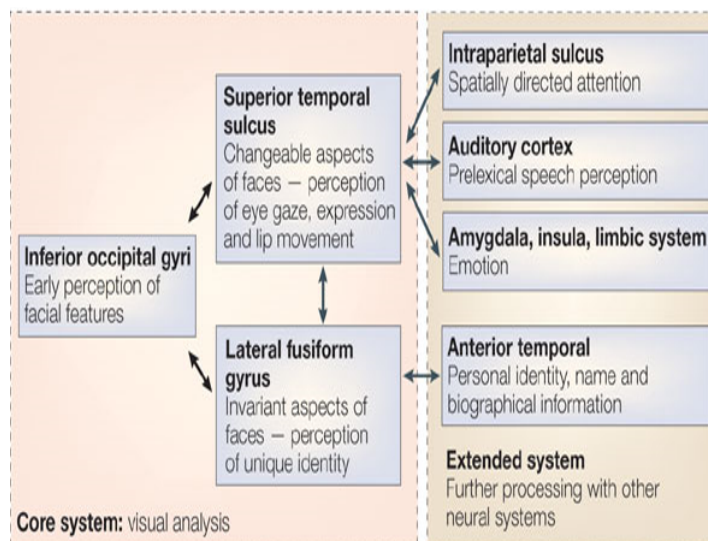


Figure 1.3: The face perception model of Haxby(2000)[9](refer from Calder & Young(2005)[8]).



## 1.2 Face pareidolia

Humans have an excellent ability to face perception. For example, even a casual pattern, such as a stain on the ceiling or a cloud, may appear like a face. The phenomenon, i.e., seeing objects as a face, is called pareidolia. Notably, the phenomenon where humans tend to see faces in non-face objects is called Face Pareidolia. However, the detailed mechanisms of this phenomenon have not been clarified.

Originally, the Pareidolia phenomenon is a kind of psychological phenomenon that refers to “a phenomenon that is considered meaning different from its original meaning in meaningless patterns, landscapes, and objects.” In general, even when this phenomenon occurs, the perception that the object has been misrecognized is maintained and experienced even if the consciousness is clear.

### 1.2.1 Perception model

The fundamental cognitive mechanism of the pareidolia phenomenon is based on the face perception process. When humans see an object, they unconsciously judge whether it is a human face or not. This ability to recognize a face is a high-level recognition function of humans. In face perception, our brain conducts featural processing that recognizes from facial elements such as “eyes, nose, and mouth” and holistic processing that recognizes from the arrangement of the facial elements. In particular, holistic processing is related to the pareidolia phenomenon [12]. This phenomenon depends on the face arrangement rather than the face element. Therefore, this phenomenon is considered a relatively low-level cognitive process. However, recently, it has been thought that this phenomenon is due to the high-level cognitive process that occurs because of the influence of the top-down process [13]. Liu et al. found that the pareidolia phenomenon occurred even when random noise images did not have facial features; the activation of the occipital region was associated with face perception, and the prefrontal cortex was related to high-level cognitive functions such as executive function.

A few studies suggest the inferior occipital gyri and the right fusiform face area are associated with the face pareidolia in the neural pathway of the pareidolia mechanism [13] [14]. It has been demonstrated that stimulating these regions (face-selective regions) in the left or right hemisphere with TMS has made face categorization difficult [15] [16]. It is conceivable that face categorization is performed in these areas. These studies suggest that the categorization process of perceptual stimuli requires identification (providing different responses to stimuli belonging to different categories) and generalization (providing similar responses to different stimuli in the

same category) [17]. Generalization processing, not identification processing of categorization processing, contributes to the pareidolia phenomenon. Because the categorization process is robust against the classification of different categories, and it is conceivable that the classification of different categories, such as face and object categories, is performed correctly. On the other hand, since the generalization process is to determine whether the perceived object belongs to the category learned so far, it is expected that the ambiguous information such as face-likeness will be classified into the face category by the generalization.

The prefrontal cortex plays an essential role in category representation and generalization. Single-unit studies in monkeys indicate that PFC neurons encode abstract behavioral rules [18] [19] [20] and are involved in context-sensitive decision making [21], and PFC processes the abstract rules beyond specific details of sensory and motor outputs and generalizes these rules in new contexts [22]. This feature allows PFC to perform essential functions in category learning and generalization. As mentioned above, PFC has been shown to have an essential contribution to the pareidolia phenomenon, suggesting that generalized processing has dramatically contributed to the occurrence of the pareidolia phenomenon.

### 1.2.2 Relationship to other perception

This pareidolia phenomenon affects not only visual illusions but also our behavior. Takahashi et al. demonstrated that gaze cueing effect and joint attention, which are essential in communication, are caused by this phenomenon [23] [24], and visual detection is increased by this phenomenon [25]. This phenomenon is also known to occur in front of the car. Klatt et al. found that the impression such as “cool” and “cute” to the design of the front of the car affects the behavior of pedestrians [26]. Moreover, Guido et al. showed that advertisements with pareidolic faces are preferred than those without pareidolic faces [27]. Therefore, the pareidolia phenomenon is closely related to our social life, and it has been used in marketing and design for improving the intimacy of objects.

### 1.3 Approaches

We investigated the neural mechanism of the pareidolia phenomenon using the psychophysical methods, EEG, and Pupillometry. First, we examined the occurrence dynamics of the pareidolia phenomenon using EEG components related to face processing (Chapter 2). We hypothesized that the EEG components could be used to clarify the pareidolia phenomenon mechanism and dynamics since the EEG component contributes to face processing such as latency, featural processing, and holistic processing. Next, because the pareidolia phenomenon might be a special categorization in the face and object categorization process, we focused on the categorization process in the pareidolia phenomenon. Since this categorization process changes not only by bottom-up processing but also by top-down modulation, we investigated the categorization processing of face-likeness from both sides. Subsequently, we clarified the effects of bottom-up processing and top-down modulation of the pareidolia phenomenon using the pupil diameter response (Chapter 4). It has been reported that the pupil diameter response is changed by the Bottom-up processing and Top-down modulation of the face processing, and both sides of the Bottom-up process and Top-down modulation in the pareidolia phenomenon are clarified by pupillometry. In addition, since human faces are known to affect our behavior, it is conceivable that they also affect our behavior when the pareidolia phenomenon occurs. The behavior associated with the pareidolia phenomenon was investigated by psychophysical methods (Chapter 5). By combining these biosignals and behavioral data, we clarified the neural mechanisms of the pareidolia phenomenon and behavioral changes caused by the pareidolia phenomenon.

### 1.4 Overview

This thesis comprises four studies (Chapter 2–5). First, we present what the pareidolia phenomenon is, how we perceive an object as a face, and the goal and approaches of this study in this chapter. Next, in Chapter 2, we present how the pareidolia phenomenon is processed in our brain using EEG. Then, in Chapters 3, 4, and 5, we present the bottom-up process and top-down modulation for the pareidolia phenomenon. Our main focus in these chapters is the differences in the brain and behavior between before and after the face pareidolia phenomenon. As shown in Chapter 3, we investigated how both aspects of bottom-up processing and top-down modulation contribute to face-likeness perception using EEG. Moreover, as shown in Chapter 4, we investigated the top-down modulation for the pareidolia phenomenon using pupil response. Furthermore, as shown in Chapter 5, we investigated how the pareidolia phenomenon effects

on preference. Finally, we summarize the outcomes of the four studies in the final chapter.

## Chapter 2

# Temporal dynamics of the face pareidolia

### 2.1 Introduction

Faces are the most important visual stimuli for social communication. When humans see each other's faces, personal information can be read immediately, and emotions can be understood from facial expression and color. In this way, face perception is valuable for humans. In addition, people tend to find faces unconsciously, even in objects (e.g., ceiling stains, clouds in the sky, etc.). Even infants preferentially watch face-like objects [28]. This phenomenon is called “face pareidolia,” and is a kind of visual illusion, not a hallucination. How, then, do humans perceive face-likeness in non-face objects?

Brain functions related to face processing have been studied using neuroimaging, including functional magnetic resonance imaging (fMRI) and electroencephalography (EEG). Whereas fMRI has high spatial resolution and identifies the brain areas related to face processing [29] [9] [13], EEG has high temporal resolution and can be used to examine dynamic processes [30]. Some EEG-based face studies have also utilized event-related potentials (ERP); some ERP components have been reported to be related to face processing. P1 is an early positive component, peaking at around 100 ms, which is sometimes larger in response to faces than objects [31] [32] [33] [34]. A more face-sensitive response was found at the level of the N170, peaking at approximately 160 ms over the occipito-temporal sites [30] [35]. The N170 component is larger for faces than for all other objects, especially in the right hemisphere [30] [35]. Moreover, this component is sensitive not only to human faces, but also to schematic faces [36] [37]. It is therefore considered to be intimately involved in face processing. Fur-

thermore, the N170 differs between hemispheres [30] [38] [39]; the amplitude is larger in the left hemisphere for featural processing (eyes, nose, and mouth), and in the right hemisphere for configure/holistic processing [40] [9] [39]. In addition, the N250, peaking at 250–300 ms, subsequent to the N170 component, is sensitive to face identity [41] [42].

Conversely, face inversion effects have been well studied for specific face recognition. This phenomenon disrupts face recognition when face stimuli are inverted 180°. Moreover, the disruption effect is larger for face stimuli than for other object stimuli [43]. There is evidence that configural/holistic [44] [45] processing of human faces is disrupted by inversion [44] [46] [47] [48]. Reed et al. [49] reported slower reaction times (RTs) and higher error rates for decisions about inverted faces than for those about upright faces. This effect is observed in brain activity as well as in behavior [30]. The N170 and P1 components are larger with presentation of inverted face stimuli, but not with that of inverted object stimuli [50] [32]. Some previous studies have reported that the amplitudes of the P1 and N170 components increased and the latencies were delayed with presentation of inverted face images, as compared to upright face images, which suggested that the P1 component is an early indicator of endogenous processing of visual stimuli, and that the N170 component reflects an early stage of configural/holistic encoding, and is sensitive to changes in facial structure [32]. In addition, some studies have suggested that upright faces are dominated by holistic processing, and inverted faces by featural processing [39]. For example, Rossion et al. [51] [52] [53] reported that N170 inversion effects disrupted processing of configural/holistic information. This effect is considered as a marker for special processing of upright face stimuli in the brain [54] [55]. Moreover, another study suggested that the inversion effect of N170 amplitude is category-sensitive [56]. These results suggest that the inversion effect is a marker for face-like processing.

Other previous studies investigating holistic and featural processing during face processing of inverted faces, using realistic and schematic images, reported that the N170 amplitude increased when inverted realistic face images were presented [41]. Conversely, the N170 amplitude decreased when inverted schematic face images were presented. This study theorized that schematic faces that did not have enough featural information were recognizable by holistic processing when presented upright. However, when the images were inverted, the N170 amplitude was reduced due to preferential featural processing instead of configural/holistic processing. This suggested that individuals perform holistic processing in response to upright faces and featural processing in response to inverted faces.

Facial inversion effect studies have investigated face-like objects as well as faces. 1 study investigated holistic processing using face images; Arcimboldo paintings consisting of vegetables, fruits, and books; and object images (e.g., a car and a house) [39]. In the upright stimuli,

Arcimboldo paintings and face stimuli induced larger N170 amplitudes in the right hemisphere than did object stimuli. In contrast, in the left hemisphere, N170 amplitudes differed between processing of Arcimboldo paintings and face stimuli. This suggested that the right hemisphere is related to holistic processing, and the left hemisphere to feature processing.

Previous studies also suggested that face-like objects were processed in the N170 component in the right hemisphere, through holistic processing [39] [57]. Furthermore, Churches et al. [58] suggested that the amplitude of the N170 component in response to objects is affected by the face-likeness of the objects. In addition, previous studies also suggested that the P1 component is associated with face-likeness processing. Dering et al. [59] reported that the amplitude of the P1 component was modulated in a face-sensitive fashion-independent cropping or morphing. This means that P1 is sensitive to face processing. However, it is unclear whether the P1 and N170 components contribute to face-likeness judgment. Additionally, although these studies investigated how facial features and positions of facial parts are processed, how and when face-likeness perception is processed was not known. According to Sagiv and Bentin [41], Churches et al. [58] and Caharel et al. [39], the N170 component may reflect face-likeness, because the N170 component reflects an early stage of structure coding and is sensitive to face-like stimuli, such as Arcimboldo paintings.

In this study, we investigated whether the inversion effect index of the N170 component actually reflected face-likeness, by observing the correlation between the ERP components and behavioral reports of face-likeness. We expected that correlation between the inversion effect index of N170 amplitude and face-like scores would be found. Furthermore, P1 and N250 correlate with face-like scores, similar to the N170 component. Taken together, this study investigated face-likeness judgment as reflected by ERP components, as well as how and when face-like objects are processed. The purpose of this study was to reveal which ERP components contribute to face-likeness judgment based on correlation between face-likeness evaluation scores and the inversion effect of each ERP component.

## 2.2 Materials and methods

### 2.2.1 Participants

Twenty-one healthy, right-handed volunteers (age: 19–37 years, 3 female) with normal or corrected-to-normal vision participated in the experiment. Informed written consent was obtained from participants after procedural details had been explained. The Committee for Human Research of Toyohashi University of Technology approved experimental procedures.

### 2.2.2 Stimuli

The stimuli in each category are shown in Figure 2.1. There were 4 categories of stimuli, including natural human faces (without glasses or make-up, and with a neutral expression), Arcimboldo paintings, insects (animate category), and cars (inanimate category). The face category was selected from the FACES database (Max Planck Institute for Human Development, Berlin; [60]). Each category consisted of 6 kinds of stimuli. In the face category, we presented equal numbers of male and female faces. Only faces with neutral expression were chosen (interrater agreement  $N = 0.90$ , as published for the reference sample). The upright orientation of the insect category was defined as erecting a higher face-likeness evaluation score in the image evaluation experiment. All photographs were converted to gray scale, and mean luminance and size were equalized with Adobe Photoshop® CS2 software. All stimuli were  $220 \times 247$  pixels (visual angle  $9.7$  to  $11.6^\circ$ ). Each stimulus was presented in 2 different orientations, either upright or inverted  $180^\circ$ .

### 2.2.3 Procedure

After electrode-cap placement, participants were seated in a light- and sound-attenuated room, at a viewing distance of 60 cm from a computer monitor. Stimulus presentation was controlled by a ViSaGe system (Cambridge Research System, Rochester, UK) and presented on a CRT monitor (EIZO, Flexscan-T761, graphics resolution  $800 \times 600$  pixels, frame rate: 100 Hz). Stimuli were displayed at the center of the screen on a light gray background. At the start of each trial, a fixation point appeared in the center of the screen for 500 ms, followed by the presentation of the test stimulus for 500 ms. The inter-trial interval was randomized between 1,000 and 1,500 ms. Participants performed face-like evaluation tasks and provided their responses by pressing 1 of 7 keys on a numeric keyboard with their right or left index finger; right or left was counterbalanced across blocks (right to left or left to right). They rated face-likeness on a 7-point scale from 1 (non-face-like) to 7 (most face-like) and were requested to respond within 3,000 ms. Participants were instructed to maintain eye gaze fixation on the center of the screen throughout the trial and respond as accurately and as quickly as possible. Participants performed 96 trials per condition (6 stimuli in each category repeated 16 times in each orientation). Four blocks of 192 trials (4 categories  $\times$  6 stimuli  $\times$  2 orientations  $\times$  4 times) were presented in a pseudo-random order. Thus, participants performed a total of 768 trials.



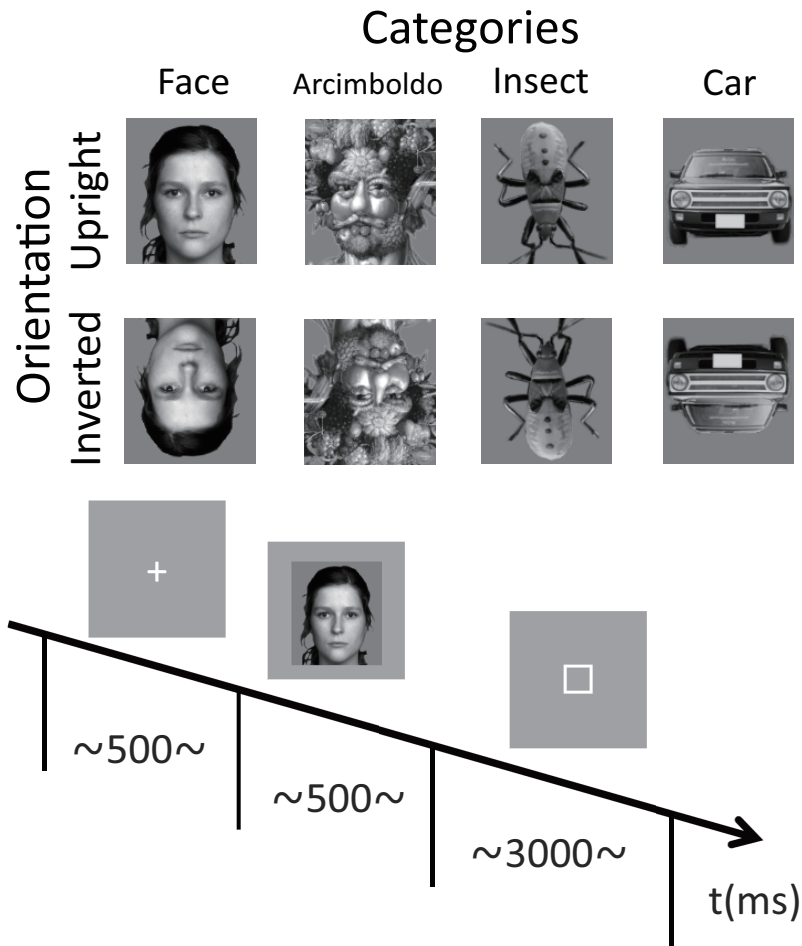


Figure 2.1: Example stimuli for each category and the timeline of stimulus presentation during a single trial. The face category was selected from the FACES database (Max Planck Institute for Human Development, Berlin; [60]). Only faces with neutral expression were chosen (interrater agreement  $N = 0.90$ , as published for the reference sample). The car category was selected as representing artificial objects, and the insect category was selected as representing natural objects. The Arcimboldo paintings were selected for observing holistic and feature processing, as described by Caharel et al. (2013) [39] and Rossion et al. (2011) [35]. Images for each condition were randomly presented, and the participants performed the face-likeness evaluation task.

### 2.2.4 EEG-recording

EEG data were recorded with 64 active Ag-AgCl sintered electrodes mounted on an elastic cap according to the extended 10–20 system and amplified by a BioSemi ActiveTwo amplifier (BioSemi; Amsterdam, The Netherlands). Electrooculography (EOG) was recorded from additional channels (the infraorbital region of right eye, and the outer canthus of the right and left eye). Both the EEG and the EOG were sampled at 512 Hz.

### 2.2.5 Data acquisition

#### Behavioral data

Scores (face-likeness) and reaction times (RTs) were computed for each condition and submitted to repeated ANOVAs with category (faces, Arcimboldo paintings, insects, cars), and orientation (upright vs. inverted) as within-subject factors.

#### EEG data

For ERP analysis, a 1–30 Hz digital band-pass filter was applied offline to continuous EEG data after re-referencing the data to an average reference using the EEGLAB toolbox [61]. The continuous EEG data were divided into 900 ms epochs (–100 to +800 ms from stimulus onset) and baseline corrected (–100 to 0 ms). Correction for artifacts, including ocular movements, was performed using Independent Component Analysis (ICA) (runica algorithm) as implemented in the EEGLAB toolbox. ICA decomposition was derived from all trials concatenated across conditions. Ocular artifacts were removed from each average by ICA decomposition [62]. Subsequently, 4 methods of artifact rejection were performed. First, artifact epochs were rejected based on extreme values in the EEG channel,  $\pm 80 \mu\text{V}$ . Next, artifacts based on linear trend/variance using the EEGLAB toolbox (max slope [ $\mu\text{V}/\text{epoch}$ ]: 50; R-squared limit: 0.3) were rejected. Artifact epochs were also rejected using probability methods (single- and all-channel limits: 5 SD) and kurtosis methods (single- and all-channel limits: 5 SD), again using the EEGLAB toolbox. Grand-mean ERP waveforms were visually assessed and peak amplitude and latency were extracted. Peak amplitude and latency of P1, N170, and N250 components were extracted at a maximum amplitude value between 80 and 130 ms for the P1 and at the minimum amplitude value between 130 and 200 ms for the N170 and at a minimum amplitude value between 220 and 300 ms for the N250, for different pairs of occipito-temporal electrodes in the left and right hemispheres: 3 left hemisphere electrodes (P5, P9, PO7) and 3 right hemisphere electrodes (P6, P10, PO8). Moreover, the topographies were calculated to assess which

electrode optimized the analysis in this study. The topographies were calculated by averaging across 4 categories and the relevant time window of each ERP component. Amplitude and latency of the P1, N170, and N250 were submitted to separate repeated-measure ANOVAs with category, orientation, and hemisphere as within-subject factors and post-hoc analysis was performed by using Bonferroni method.

### Inversion effect

We calculated the inversion effect index using the following equation 2.1. Each ERP component was assigned to the formula [63] [64]. The inversion effect index showed differences in N170 amplitudes between the upright and inverted conditions divided by the sum of the 2 conditions. If a normal face inversion effect occurs, this index should be negative. Each inversion effect index was evaluated by means of a 1-sample t-test to determine whether the effect was significantly different from 0. Furthermore, the inversion effect index values were computed for each condition and submitted to repeated ANOVAs with hemisphere and category as within-subject factors (Figure 2.5).

$$FII = \frac{|Amp_{Upright}| - |Amp_{Inverted}|}{|Amp_{Upright}| + |Amp_{Inverted}|} \quad (2.1)$$

### Correlation analysis

Pearson's correlation analysis was performed between the inversion effect index for each ERP component and the mean face-like score (the mean between upright and inverted score) using the robust correlation toolbox [65]. The toolbox automatically implements the Bonferroni adjustment for multiple comparisons for each test and provides bootstrapped confidence intervals for the correlations themselves. For the inversion effect index, we calculated the value from each category for each ERP component in each participant.

## 2.3 Results

### 2.3.1 Behavioral results

Participants responded more strongly to faces than to images in other categories (Figure 2.2). There were main effects of Category [ $F(3, 60) = 204.255, p < 0.001, \eta^2 = 0.91$ ] and Orientation [ $F(1, 20) = 78.166, p < 0.001, \eta^2 = 0.80$ ], and an interaction between these factors [ $F(3, 60) = 15.660, p < 0.001, \eta^2 = 0.44$ ]. This interaction showed a significant effect of Category for both

orientations [Upright:  $F(3, 60) = 193.770, p < 0.001, \eta^2 = 0.90$ , Inverted:  $F(3, 60) = 6.480, p = 0.001, \eta^2 = 0.24$ ]. For Orientation, the scores of all categories showed a significant difference between upright and inverted orientations ( $p < 0.001$ , for all). For both orientations, scores were higher for faces than for other image categories (respectively,  $p < 0.001, p < 0.001$ , and  $p < 0.001$ , for both orientations) and the scores for Arcimboldo paintings were higher than those for insects and cars (respectively,  $p < 0.001$  and  $p < 0.001$ , for both orientations). However, there was no significant difference between the car and insect categories. This interaction showed a significant effect of Orientation for all categories [Face :  $F(1, 20) = 441.970, p < 0.001, \eta^2 = 0.95$ , Arcimboldo:  $F(1, 20) = 431.200, p < 0.001, \eta^2 = 0.95$ , Insect:  $F(1, 20) = 71.580, p < 0.001, \eta^2 = 0.78$  and Car:  $F(1, 20) = 63.650, p < 0.001, \eta^2 = 0.76$ ]. Moreover, participants responded more quickly to faces to other types of images. A main effect was found for Category [ $F(3, 60) = 32.634, p < 0.001, \eta^2 = 0.62$ ] and Orientation [ $F(1, 20) = 5.010, p = 0.037, \eta^2 = 0.20$ ]. Moreover, an interaction was found between Category and Orientation [ $F(3, 60) = 5.703, p = 0.002, \eta^2 = 0.22$ ]. This interaction showed a significant effect of Orientation for face category [ $F(1, 20) = 66.890, p < 0.001, \eta^2 = 0.77$ ] and Arcimboldo paintings category [ $F(1, 20) = 49.820, p < 0.001, \eta^2 = 0.71$ ]. This Category  $\times$  Orientation interaction revealed that the response time to faces and Arcimboldo paintings was delayed for inverted orientations as compared to upright orientations ( $p < 0.001$ ). Furthermore, this interaction showed a significant effect of Category for upright orientation [ $F(3, 60) = 85.570, p < 0.001, \eta^2 = 0.81$ ]. Participants responded more quickly to faces than to other image categories in the upright orientation (respectively,  $p < 0.001, p < 0.001$ , and  $p < 0.001$ ). However, there were no significant differences between Arcimboldo vs. Insect, Arcimboldo vs. Car, and Insect vs. Car.

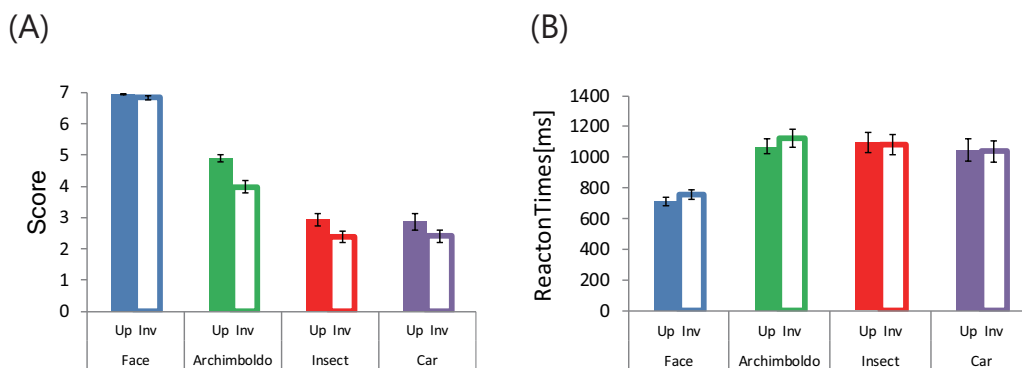


Figure 2.2: (A) Each bar indicates the mean face-likeness score for each category in the upright (fill) and inverted (no fill) orientations. (B) Each bar indicates the mean reaction times for each category in the upright (fill) and inverted (no fill) orientation.

### 2.3.2 Event-related potential

#### P1 Component

Figures 2.2, 2.3 show the topographies and the ERP waveforms in the 6 channels (Left: PO7, P9, P5; Right: PO8, P10, P6). Clear peaks of P1, N170, and N250 are observed. ANOVAs of P1 amplitudes showed a main effect for Category [ $F(3, 60) = 2.935, p = 0.035, \eta^2 = 0.13$ ] and Orientation [ $F(1, 20) = 22.751, p < 0.001, \eta^2 = 0.53$ ]. The main effect of Category indicated that P1 amplitude for the insect category was smaller for Arcimboldo and car categories (respectively,  $p < 0.001$  and  $p = 0.005$ ). The main effect of Orientation revealed that the P1 amplitude was larger for inverted orientations than for upright orientation ( $p < 0.001$ ). ANOVAs for P1 latency showed a main effect for Category [ $F(3, 60) = 8.565, p < 0.001, \eta^2 = 0.30$ ], Orientation [ $F(1, 20) = 13.554, p = 0.001, \eta^2 = 0.40$ ], Hemisphere [ $F(1, 20) = 11.514, p = 0.003, \eta^2 = 0.37$ ], and an interaction between Category  $\times$  Orientation [ $F(3, 60) = 7.583, p < 0.001, \eta^2 = 0.28$ ]. This interaction showed a significant effect of Orientation for the face category [ $F(1, 20) = 23.44, p < 0.001, \eta^2 = 0.54$ ] and the car category [ $F(1, 20) = 5.11, p = 0.035, \eta^2 = 0.20$ ]. Moreover, this interaction showed a significant effect of Category for both orientations [Upright:  $F(3, 60) = 6.37, p = 0.001, \eta^2 = 0.24$ , Inverted:  $F(3, 60) = 11.31, p < 0.001, \eta^2 = 0.36$ ]. The P1 latency in response to upright orientations was shorter for the face category than for the Arcimboldo paintings category ( $p = 0.031$ ), and the P1 latency in response to inverted orientations was shorter for the insects category than for other categories (respectively, face:  $p = 0.017$ , Arcimboldo paintings:  $p = 0.003$ , and car:  $p < 0.001$ ).

#### N170 Component

ANOVAs for N170 amplitude showed a main effect for Category [ $F(3, 60) = 18.613, p < 0.001, \eta^2 = 0.48$ ], Hemisphere [ $F(1, 20) = 5.907, p = 0.025, \eta^2 = 0.23$ ] and Hemisphere  $\times$  Orientation [ $F(1, 20) = 7.777, p = 0.011, \eta^2 = 0.28$ ]. This Hemisphere  $\times$  Orientation interaction revealed that the N170 amplitude in inverted orientation was larger for the right hemisphere than for the left hemisphere ( $p = 0.012$ ). In addition, a three-way interaction was found among hemisphere, category, and orientation [ $F(3, 60) = 5.464, p = 0.002, \eta^2 = 0.22$ ]. In the right hemisphere, the Category  $\times$  Orientation interaction was significant [ $F(3, 60) = 4.24, p = 0.009, \eta^2 = 0.17$ ], as the N170 amplitude for inverted orientation was larger for the face category than for other categories (respectively, Arcimboldo paintings:  $p < 0.001$ , car:  $p < 0.001$  and insect:  $p < 0.001$ ), and N170 amplitude for inverted orientation was larger for the insect category than for the Arcimboldo paintings category ( $p = 0.011$ ), with no statisti-

cally significant difference found between the insect and car categories ( $p < 1.000$ ) [Simple main effect of Category effect:  $F(3, 60) = 24.010, p < 0.001, \eta^2 = 0.54$ ]. However, for upright orientations, no significant Category effect was observed [ $F(3, 60) = 1.96, p = 0.1290, \eta^2 = 0.09$ ]. Furthermore, the N170 amplitude for the face category was larger in the inverted orientation than in the upright orientation ( $p = 0.029$ ). In the left hemisphere, no significant interaction was observed [ $F(3, 60) = 1.14, p = 0.3420, \eta^2 = 0.05$ ]. ANOVA results for the N170 latency showed a main effect for Orientation [ $F(1, 20) = 17.947, p < 0.001, \eta^2 = 0.47$ ], Category [ $F(1.855, 37.100) = 23.194, p < 0.001, \eta^2 = 0.54$ ], and Category  $\times$  Orientation [ $F(3, 60) = 13.996, p < 0.001, \eta^2 = 0.41$ ]. This Category  $\times$  Orientation interaction showed a significant effect of Category for both orientations [Upright:  $F(3, 60) = 39.35, p < 0.001, \eta^2 = 0.66$ , Inverted:  $F(3, 60) = 8.64, p < 0.001, \eta^2 = 0.30$ ]. This interaction revealed that the N170 latency in response to upright orientations was shorter for the face category than for other categories ( $p < 0.001$ ), and the N170 latency in response to inverted orientations was more delayed for the car category than for the other categories ( $p < 0.001$ ). Furthermore, latency in response to face category in the upright orientation was shorter than for the inverted orientation ( $p < 0.001$ ), and the latency in response to the car category in the upright orientation was shorter than for the inverted orientation ( $p < 0.001$ ).

### N250 Component

ANOVA results for the N250 amplitude showed a main effect for hemisphere [ $F(1, 20) = 4.837, p = 0.040, \eta^2 = 0.20$ ] and category [ $F(2.220, 44.394) = 3.639, p = 0.030, \eta^2 = 0.15$ ]. The N250 amplitude was larger for the right hemisphere than for the left hemisphere ( $p < 0.001$ ). In addition, there was a significant interaction between Category and Hemisphere [ $F(3, 60) = 3.649, p = 0.017, \eta^2 = 0.15$ ] and between Category and Orientation [ $F(3, 60) = 3.852, p = 0.014, \eta^2 = 0.16$ ]. The Category  $\times$  Orientation interaction showed a significant Category effect for inverted orientation [ $F(3, 60) = 6.16, p = 0.001, \eta^2 = 0.24$ ]. The N250 amplitude for inverted orientation was larger for the car category than for the Arcimboldo paintings and insect categories ( $p < 0.05$ ). Moreover, this interaction showed an orientation effect for face and car categories [Face:  $F(1, 20) = 7.91, p = 0.011, \eta^2 = 0.28$  and Car:  $F(1, 20) = 5.85, p = 0.028, \eta^2 = 0.22$ ]. The N250 amplitude for the face category was larger for the inverted orientation than for the upright orientation and the N250 amplitude for the car category was larger for the inverted orientation than for the upright orientation. The Category  $\times$  Hemisphere interaction showed a significant Category effect for the right hemisphere [ $F(3, 60) = 3.74, p = 0.016, \eta^2 = 0.16$ ]. The N250 amplitude in the right hemisphere was larger

for the car category than for the insect category. Moreover, this interaction showed a Hemisphere effect for the face category. The N250 amplitude for the face category was larger in the inverted orientation than in the upright orientation ( $p = 0.002$ ). ANOVA results for N250 latency showed no significant effect and interaction.

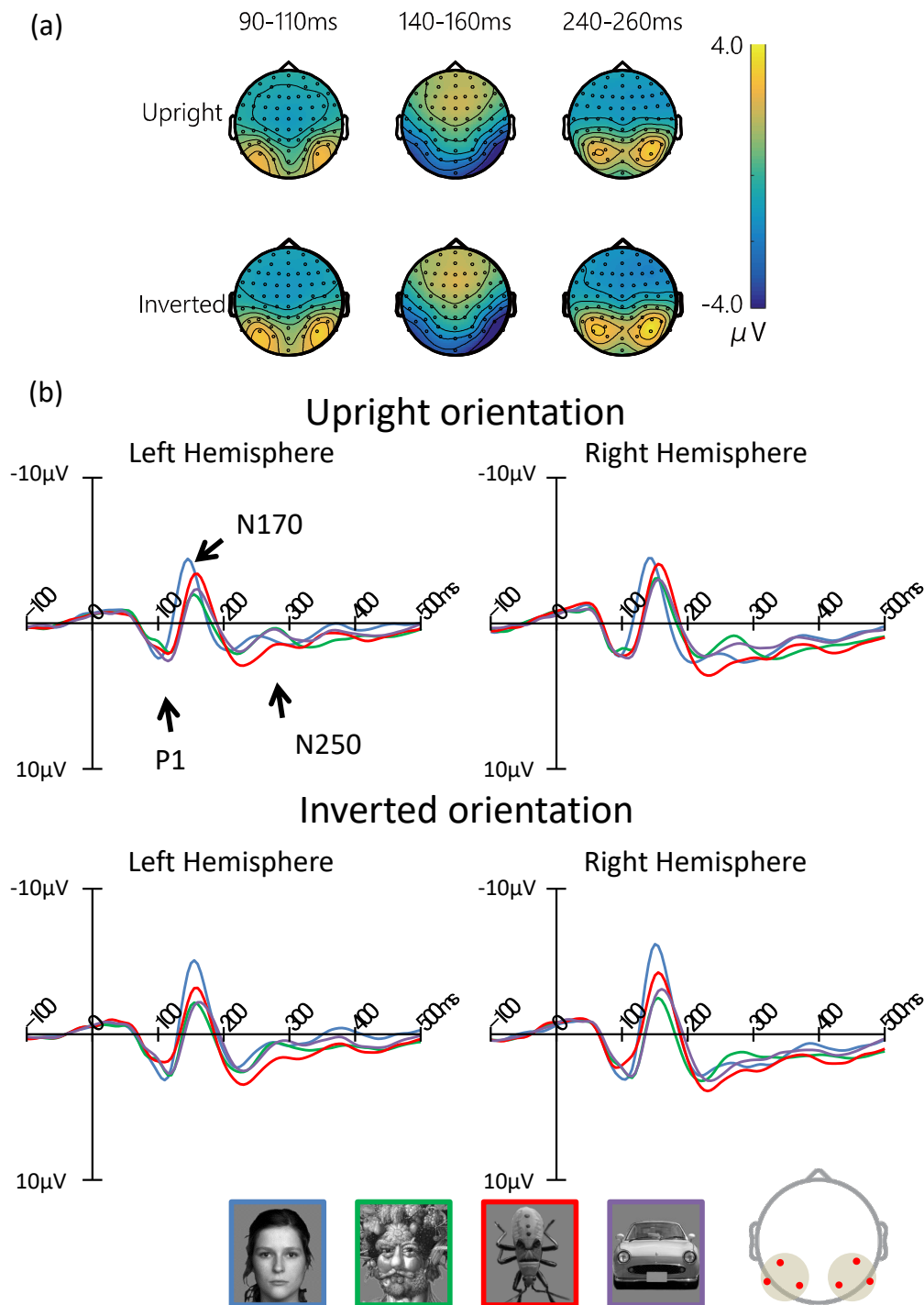


Figure 2.3: The grand average of ERP waveforms elicited by each category in the upright and inverted orientations at the left and right pooled occipito-temporal electrode sites (waveforms averaged for electrodes P5/P9/PO7, P6/P10/PO8).



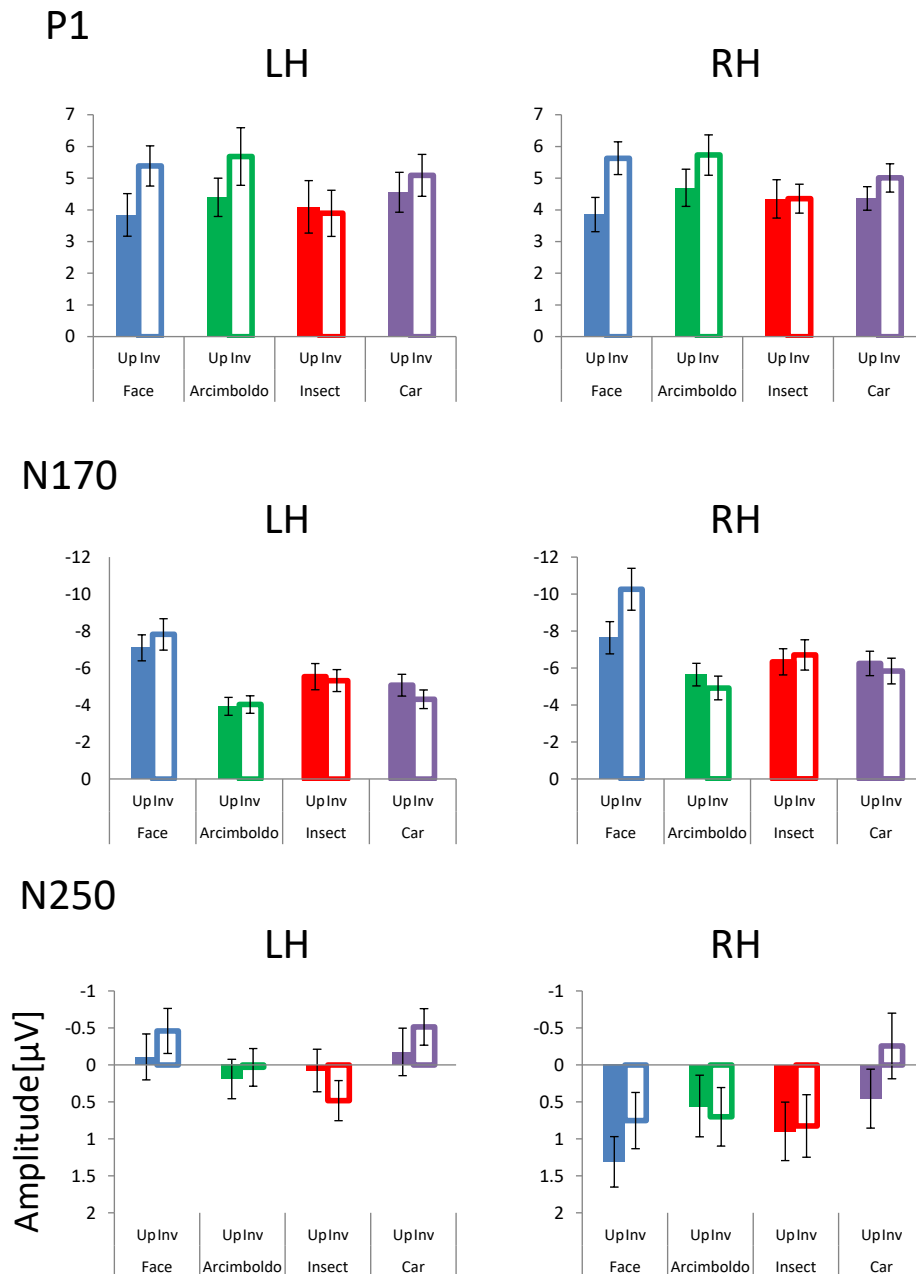


Figure 2.4: The peak amplitude of the P1 (Top), N170 (Middle), and N250 component (Bottom) measured at the left and right pooled occipito-temporal electrode sites (averaged for electrodes P5/P9/PO7 and P6/P10/PO8), displayed for 4 categories in the upright (fill) and inverted (no fill) orientations.

### 2.3.3 Face inversion effect index

#### P1 Component

The inversion effect index of the P1 component was then compared with a 1-sample t-test against zero, showing a significant index for face category in both hemispheres, Arcimboldo painting category in the right hemisphere, and car category in the left hemisphere ( $p < 0.05$ ). The P1 component showed a main effect of Category [ $F(2.076, 41.510) = 3.709, p = 0.032, \eta^2 = 0.16$ ]. The inversion effect index was larger for the face category than for the insect and car categories (respectively,  $p = 0.002$  and  $p = 0.006$ ).

#### N170 Component

The inversion effect index of the N170 component was then compared with a 1-sample t-test against zero, showing a significant index for face category and Arcimboldo painting category in the right hemisphere ( $p < 0.05$ ). For the N170 component, no effect was found for Hemisphere [ $F(1, 20) = 0.344, p = 0.564, \eta^2 = 0.02$ ], Category [ $F(3, 60) = 2.372, p = 0.079, \eta^2 = 0.11$ ], or the interaction between Hemisphere and Category [ $F(3, 60) = 2.228, p = 0.094, \eta^2 = 0.10$ ].

#### N250 Component

The inversion effect index of the N250 component was then compared with a 1-sample t-test against 0; a significant index for only the car category in the left hemisphere ( $p < 0.05$ ) was found. The N250 component showed a main effect of Hemisphere [ $F(1, 20) = 5.770, p = 0.026, \eta^2 = 0.22$ ]. The inversion effect index was larger in the right hemisphere than in the left hemisphere. Moreover, there was a significant interaction between Hemisphere and Category [ $F(3, 60) = 3.948, p = 0.012, \eta^2 = 0.17$ ]. This Hemisphere and Category revealed that the inversion effect index in response to car was larger for the right hemisphere than for the left hemisphere ( $p < 0.05$ ).

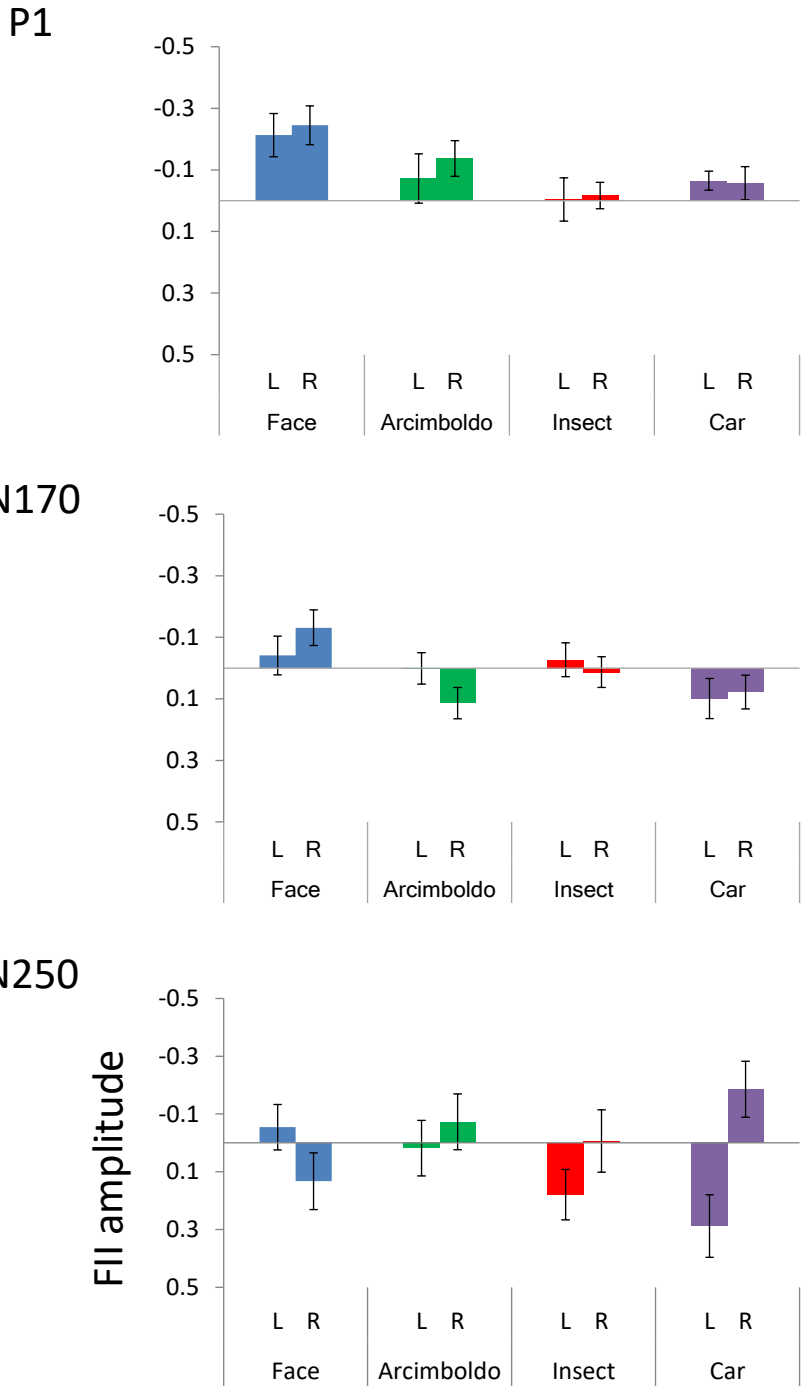


Figure 2.5: The inversion effect index for peak amplitude of the P1 (Top), N170 (Middle), and N250 (Bottom) components, measured at the left and right pooled occipito-temporal electrode sites (averaged for electrodes P5/P9/PO7 and P6/P10/PO8) and displayed for 4 categories. correlation

### 2.3.4 Correlation analysis

We performed a correlation analysis to explore the relationship between the face-like score and the inversion effect index (see Figure 2.6). In the P1 component, a significant correlation was observed between the inversion effect index and face-like score in both hemispheres (left:  $r = -0.273, p < 0.05$ , right:  $r = -0.307, p < 0.05$ ). Furthermore, in the N170 component, a significant correlation was observed between the inversion effect index and face-like score in the right hemisphere ( $r = -0.282, p < 0.05$ ). In contrast, the N250 components showed no significant correlation. The results indicate that the face-likeness judgment affects early face processing, especially for the right hemisphere. In addition, we also performed a correlation analysis to explore the relationship between the face-like score and raw ERP component (each orientation) or each ERP latency.

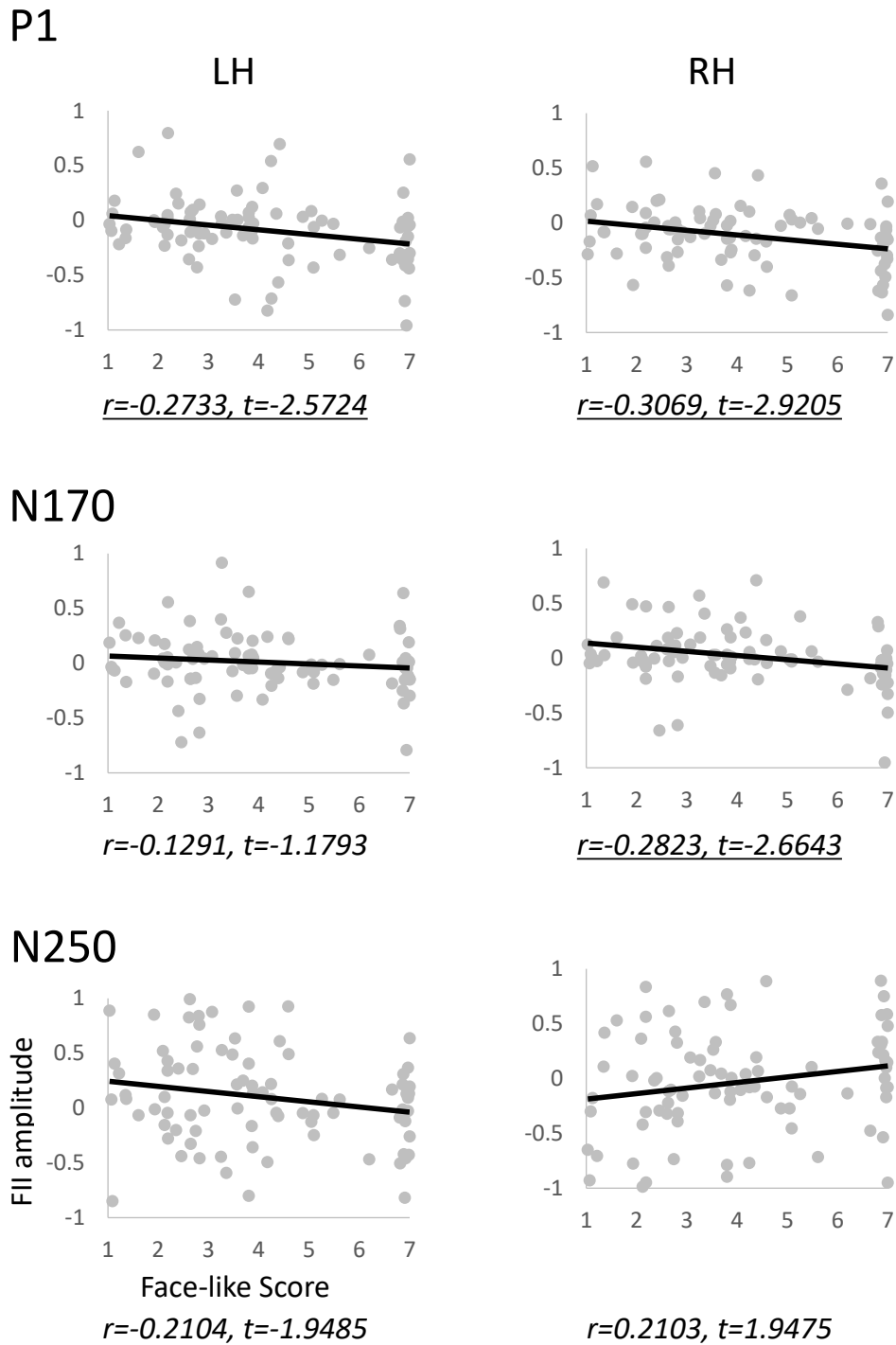


Figure 2.6: Correlation map between the inversion effect index and the face-likeness score of P1 (Top), N170 (Middle), and N250 (Bottom) components, calculated for the left (left side) and right (right side) hemispheres. The vertical axis indicates the inversion effect index value, and the horizontal axis indicates the face-likeness scores. Underlines indicate significant correlations.

## 2.4 Discussion

The present study investigated brain activity reflecting face-likeness and explored the correlation between the face inversion effect and face-like score. Significant correlation was observed for P1 in both hemispheres and N170 in the right hemisphere. These results suggest that face-likeness judgment affects early visual processing. After this processing, face-like objects are processed by holistic processing in the right hemisphere. Furthermore, these results suggest that the face inversion index can be used as indicator of face-likeness in early face processing.

### 2.4.1 Behavior

Behavioral results showed that face-like scores were reduced in response to inverted objects. Conversely, the scores of human faces in inverted orientations were almost the same as those in upright orientations. Similarly, Reed et al. [49] reported slower RTs and higher error rates for decisions about inverted human faces, compared to those for upright faces. Furthermore,

Itier et al. [66] reported lower error rates of behavioral inversion effects for natural human faces than for other objects, schematic faces, and Mooney faces, two-toned, ambiguous face images. Their results are consistent with our findings that showed that the inversion effect was specific to face processing, as compared with processing of other object categories.

### 2.4.2 P1 Component

In terms of ERP results, each component (P1, N170, and N250; Figure 2.3) was observed for each category. The P1 amplitude showed an inversion effect in both hemispheres. P1 reflects the processing of low-level physical properties, including contrast, luminance, spatial frequency, and color [50] [41] [32] [39]. However, all stimuli were gray-scale images of equally calibrated luminance in this study. Furthermore, P1 affects holistic face processing [67] [68], and is selective for face parts [30]. These previous studies suggested that P1 is related to configural/holistic and featural processing, and hence, P1 amplitudes for face-like objects were almost the same as the amplitudes for face stimuli. Moreover, the Arcimboldo paintings consist of numerous objects resembling facial parts, with different local contrasts, which may be why the amplitude of the Arcimboldo painting category was higher than for other categories [32]. In addition, the face inversion effect for the P1 amplitude was consistent with the results of Boutsen et al. [30]. According to Boutsen et al. [30], the P1 component is sensitive to global face inversion. Therefore, the inversion effect for P1 appeared in both hemispheres in response to face, Arcimboldo and car categories. However, the inversion effect was not observed for the

insect category, because insect stimuli are not dependent on orientation. Thus, the difference in amplitude according to orientation, which is the inversion effect, was not observed for the insect category.

### 2.4.3 N170 Component

In terms of N170 amplitude, the ANOVA results indicated that the car and insect categories were processed similarly to the face category in the right hemisphere, because there was no difference between these categories for the upright orientation. In the inverted orientation, the amplitude for the face category was larger than for other categories, and the amplitude for the Arcimboldo category was smaller than for other categories. Interestingly enough, this relationship was observed for the inverted orientation in the right hemisphere. We considered that the inverted Arcimboldo category did not contain holistic/configural face information. These results suggested that the Arcimboldo category underwent another form of processing, which was neither face processing nor object processing. In the left hemisphere, we observed no significant difference for either factor. However, the amplitude in response to the objects category was smaller than in response to the face category. These results were consistent with previous studies suggesting that the left hemisphere is specialized for analytic processing of local features of the face Boutsen et al. [35]. Moreover, the face inversion effect for N170 appeared in both hemispheres in response to only the face category. In the face category, the results were consistent with the study of Itier and Taylor [32], suggesting that the amplitude was increased and the latency was delayed by inverted orientation. In the Arcimboldo category, the results were consistent with the study of Caharel et al. [39], suggesting that the amplitude decreased in the right hemisphere and the latency was delayed.

### 2.4.4 N250 Component

There was a difference in the N250 amplitude between the 2 hemispheres. The N250 component relates to personal detection processing in the right hemisphere [69]. This processing increased in amplitude when observing objects related to the self (e.g. friends, family, self-face), and hence, the amplitude was small in the right hemisphere in our study. In contrast, the amplitude for the left hemisphere was increased when observing familiar objects [70]. Therefore, N250 amplitudes in the left hemisphere were larger in response to faces and cars. Moreover, it may be suspected that the amplitude for the Arcimboldo category was increased because the Arcimboldo paintings resemble human faces. In contrast, the amplitude decreased in response to the insect category, because the insect images in this study were unfamiliar objects. This

component was also reported to have no inversion effect [71], perhaps because orientation processing was already performed at N170. However, the face and car categories showed a lower inversion effect, which can be attributed to the influence of N170.

### 2.4.5 Correlation

We calculated the correlation between the inversion effect index for each ERP component and the face-like score for each category. Significant correlation for the P1 component was observed in both hemispheres. This correlation suggested that the P1 component reflects face-likeness. Moreover, a significant correlation was observed for the N170 component for the right hemisphere. The configuration of stimuli may have been similar enough to human faces to cause this correlation only in the right hemisphere, suggesting that the P1 component in both hemispheres and the N170 component in the right hemisphere reflect face-likeness. Finally, no significant correlation was observed for the N250 component. However, there was a trend for correlation between the inversion effect index in the N250 and the face-like score in both hemispheres, which suggested that the N250 component is related to face-like processing.

### 2.4.6 Limitation

The limitations of this study include the low correlation coefficient for each component, although a significant correlation was observed in the P1 and N170 components. The face-like score may have been biased because the stimuli used in this study included only a real face category and 3 face-like categories, without any non-face-like category (e.g., flowers, clocks, and so on). Moreover, the correlation between the P1 inversion effect index and face-like scores could not distinguish between face-like processing and face detection. Additionally, the image of stimuli was difference in spatial frequency. Thus, we cannot deny that P1 components were influenced by spatial frequency. Moreover, recent studies suggested that the N170 component was also influenced by low-level visual information [59] [72]. Thus, N170 components were also influenced by spatial frequency and other low-level visual information. However, a significant Category effect was observed only in the inverted orientation in the 3-factor ANOVA. This amplitude difference between the upright and inverted orientation in this study was caused by inversion of the stimulus orientation. Finally, we did not consider the effect of gender differences in this experiment. Among 21 participants in this study, only 3 were female. We considered that the effect of gender would be small, considering the purpose of this study. However, a recent study suggested that females tend to detect face-ness in objects more than do males [73]. It is possible that our results could have been affected by sex differences.



### 2.4.7 Conclusions

Previous studies have suggested that face-likeness processing or face-ness detection occurred in the early visual cortex [74]. In this study, by calculating the correlation between the face-likeness evaluation on the stimulus and the inversion effect index of each ERP component, significant correlations were observed in the P1 component and the N170 component. Accordingly, these results suggested that the face-like processing or face-ness detection is performed in the early visual cortex and that these processes affect face-likeness judgment. Accordingly, we considered that face processing and face-like processing consisted of the following steps. Rough face processing, including detecting the existing shapes as eye-like, nose-like, or mouth-like, is performed in the earlier visual stages represented by P1, while detailed face processing is performed in the face detection stages represented by N170. The process of P1 to N170 components in this study may thus reflect face-likeness judgment. Furthermore, these results suggest that the face inversion index can be used as an indicator of face-likeness in early face processing.

## Chapter 3

# Categorization process of the face pareidolia

### 3.1 Introduction

#### 3.1.1 Pareidolia

Humans can extract a variety of information from visual stimuli such as faces by identifying individuals immediately by looking at their faces and reading emotions from facial expressions and facial colors. Thus, humans have excellent face recognition ability, and this good face recognition ability works not only on human faces but also on various objects. For example, even a pattern such as a cloud or electric socket may appear like a face. The phenomenon where a non-face object looks like a face is called pareidolia. The pareidolia phenomenon is thought to have developed to instantly determine whether a recognized face is an enemy or a friend. However, the underlying mechanism of the phenomenon is still unclear.

Many studies have explicitly investigated the pareidolia phenomenon to reveal the brain mechanism. However, based on the findings in these studies, it is difficult to estimate what causes this phenomenon because the pareidolia phenomenon has been induced in different situations from the real world. In a real-life circumstance, typical human adults find a face-like object automatically, i.e., without the intention to do so and without being able to suppress this visual detection process. In other words, the face-like object is detected as early as the face is. The pareidolia phenomenon is considered the innate nature of face processing [1] [2] [3] [4]. Goren et al. compared the face arrangement condition, face shape without the facial pattern condition, and correct facial pattern condition in infants study, and they found that infants

preferred the correct facial pattern condition [5]. Simion et al. suggested that newborns preferred “top-heavy” stimuli, and such bias might account for neonatal face preference [6]. The findings indicate that “top-heavy” arrangements, rather than the specific parts such as eyes, nose, and mouth, are important for face processing. In these studies, the “pattern with a face-like arrangement,” but not a real face, was used. Because of this innate nature, facial patterns, as well as real faces, should be detected automatically. In addition, a region named the Fusiform Face Area (FFA) in the brain is dedicated to face processing [75] [76] [29], and it is known to preferentially activate face patterns regardless of face perception [77].

On the other hand, some studies indicate that this pareidolia phenomenon does not occur just by looking at an object and must be recognized as a face, with top-down modulation [24] [25] [23]. In fact, this phenomenon occurs even when random noise images do not include facial features [13], and face perception and object perception are enhanced by top-down modulation [78] [79] [80]. According to these findings, the occipital area is responsible for visual processing, the occipitotemporal area is related to facial recognition (FFA and inferior frontal gyrus [IFG]), and the activities of the prefrontal cortex are related to higher cognitive functions such as executive functions. In the present study, we investigated how both bottom-up processing and top-down modulation contribute to face-likeness perception.

### 3.1.2 Perceptual categorization

Humans can immediately judge what kind of object it is by looking at the object. Especially, the ability is sharpened for the face. The rounded object is judged immediately as a face in the field of view. This ability to quickly group experienced stimuli into meaningful categories (perceptual categorization) is certainly one of the most fundamental high-level brain functions. Caldara et al. investigated the categorization of patterns with facial features using fMRI [77], and they showed that patterns with facial features activated FFA, suggesting that patterns with facial features are automatically categorized. However, in their experiments, the stimulus presentation duration was nine seconds; thus, automatic categorization was difficult.

### 3.1.3 Fast periodic visual stimulation

In the visual domain, the method that is used to investigate the perceptual categorization process combines visual periodicity with the direct recording of neural activity using EEG. By embedding members of a specific category at a strict periodic rate within a dynamic visual stream of items that do not belong to that category, the perceptual categorization process of interest is projected at a specified frequency in the EEG spectrum. This approach is an

objective and highly efficient way to separate the category-selective visual process without post-subtraction at a rapid (and quasi-continuous) rate [81] [82] [83]. For example, Lochy et al. [84] investigated the lexical categorization process by presenting participants with a stream of non-word items at a rate of exactly 10 Hz (i.e., ten non-words per second), with a word stimulus embedded with every fifth item; three minutes of this stimulation elicited an electrophysiological response at the exact frequency of image presentation (10 Hz). More importantly, the exact period of word items is embedded in non-word sequences (i.e., 10 Hz/5 items = 2 Hz); even if there is no apparent lexical decision task, this 2 Hz signal is observed and interpreted as a differential response to a word compared to a non-word because it can only occur if the response caused by a word is different from that caused by a non-word [84].

Similarly, the periodicity-based approach (Fast Periodic Visual Stimulation: FPVS) is to examine the perceptual categorization of the face and natural object images in human adults and infants [85] [17] [81] [83]. For example, Retter and Rossion [83] presented participants with a dynamic stream of object images at a rate of 12.5 Hz (i.e., 80 ms per image), with every three, five, seven, nine, or 11 face images inserted into the sequence. They observed a robust category-selective response at each of the defined face periodicities (e.g., 12.5 Hz / 7 = 1.79 Hz for every seven images), in addition to a robust response at an image presentation frequency of 12.5 Hz. This finding indicates that there is a discriminatory response to the face compared with the object. Given the highly rapid image presentation rate (each image was replaced after only 80 ms) and an entirely orthogonal task, their findings suggest that this category-selective response reflects automatic categorization of face and object at the perceptual level rather than at the decision level. This conclusion is supported by applying this approach to intracerebral recordings in a large group of human patients to identify and quantify the face-selective response in local regions of the right ventral occipitotemporal cortex [82]. Responses of interest in FPVS design depend on temporal distractors, which elicit different responses from essential stimuli, and measure the same evoked response when a critical stimulus appears using a number of highly variable images (e.g., 50 natural face images and 200 natural object images [17]), and these responses allow the visual system to distinguish essential categories in the stream from other categories [82] [17] [83]. Importantly, the dependence on the periodic response serves to minimize low-level image confounding without artificially standardizing low-level stimulus characteristics. If highly varying natural images are used, the amplitude spectra of the two categories may vary on average, but not consistently across the stimulus set. As a result, a specific set of low-level cues does not reliably occur at the frequency of the essential categories where the response of interest is measured. The observation supports this allegation that phase-scrambled natural images with preserved amplitude spectra but without structural

information do not trigger the category-selective response in FPVS designs [85] [17] [83].

An outstanding issue is whether face-likeness is categorized in a very fast stimulus presentation stream. For example, a face category-selective response embedded in a stream of objects is known to be composed of several components starting at  $\sim 100$  ms and lasting up to  $\sim 500$  ms after face onset [17] [81] [83].

It has been suggested that face detection can be achieved within 100–300 ms after the start of stimulation [86] [87] [88]. Our previous study [89] demonstrates that face-likeness is judged by about 100 milliseconds after stimulus onset. Thus, it is expected that face-likeness will be detected even in a stream of very fast stimuli. Another issue is how attention can be focused on the face. In general, experimental studies have shown that selective attention to the face enhances behavioral performance and increases neural activation. For example, Boutet et al. [90] found that individual face encoding had significant advantages when participants were asked to pay attention to the face rather than the house picture on a 50% transparency display. At the neural level, when a participant pays attention to face stimuli or performs a home matching/recognition task instead of a face, the face-selective response of the mid-FFA of the ventral occipitotemporal cortex is enhanced [91] [92] [93] [94] [95] [96] [97]. The time course of the effects of these attentions is controversial, but some studies showed face perception processing modulation only 200 ms after the start of stimulation [98] [99]. Other studies suggest that the initial stage of face perception processing that is indexed by N170 is strongly modulated by selective attention. By performing the face attention task, observers can easily create visual templates for categories based on the necessary arrangement of facial features, thus improving face-likeness detection as well as face detection.

### 3.1.4 Overview

To investigate the attentional modulation of rapid and automatic face-likeness detection captured by FPVS-EEG, participants were instructed to complete two behavioral tasks: (1) detect color changes of a central fixation cross (face-irrelevant task), which is a typical orthogonal task used in such studies [100] [101] or (2) detect the target gender face randomly embedded in the another gender face (face-relevant task). To confirm whether the face-selective response can be measured by these tasks, the face-selective response was compared using a sequence in which face stimuli appear periodically and another sequence in which face-likeness stimuli of interest appear periodically. We expected to find a significant face-selective response in face-related regions (i.e., occipitotemporal cortex, with a right hemispheric dominance); in addition, we predicted an increased face-selective response in the face-relevant task compared with the

face-irrelevant task.

## 3.2 Materials and methods

### 3.2.1 Participants

Sixteen healthy, right-handed volunteers (age: 23–30 years, 16 males) with normal or corrected-to-normal vision participated in the experiment. Informed written consent was obtained from participants after procedural details had been explained. The Committee for Human Research of Toyohashi University of Technology approved the experimental procedures.

### 3.2.2 Stimuli

The stimuli included 200 grayscale images of various non-face objects (e.g., animals, plants, objects, and structures/objects), 100 face images from the internet, and 100 face-like images, which are  $256 \times 256$  pixel. The luminance and contrast were equalized between stimuli. During the stimulation sequence, each image appeared on a uniform grey background and subtended  $9.077^\circ$  of visual angle. A small black fixation cross (subtending  $0.788^\circ$  of visual angle) overlaid the images throughout the sequence.

### 3.2.3 Procedure

The procedure was similar to that in the study Quek et al. [102]. Participants sat in a magnetic and soundproof dark room and viewed a computer monitor at a distance of 80 cm. They viewed only the fixation cross in advance for two seconds, and the stimulus sequences were then presented after a two-second fade-in. The 90-s sequence of rapid images were presented at a periodic rate of exactly 12 Hz (12 images per second), and when the stimulus sequence was completed, the presentation ended after a three-second fade-out. We used a 12 Hz stimulation rate because generic face-categorization (i.e., the detection of faces in the visual environment) can be achieved within the 83 ms image duration [83]. Moreover, it is considered that the stimulus presentation method using this frequency can dissociate the face-selective processing from general visual processing. The experiment was run using Windows 7 with a MATLAB 2017a and Psychophysics Toolbox extension [103] [104]. The contrast of each stimulus was presented sinusoidally in the range of 0% to 100–0% within 83.33 ms. In this presentation method, it is known that each stimulus is still visible at low contrast, but the perceptual interruption does not occur between images [83]. Participants were instructed to fix their gaze

on the central cross overlaid on the images during two tasks: (1) to press a key when the color of the fixation cross changes (200 ms change duration; 10 changes in each stimulation sequence; minimum 2s between consecutive changes), (2) to press a key when the target gender faces that were randomly embedded among another gender faces in each sequence (10 changes in each stimulation sequence; minimum 1.5 s between consecutive changes) were detected. The target gender faces were presented to participants before the session. In the periodic face stimulation sequence, face-like stimuli were randomly embedded in the sequence, and face stimuli were presented with a period of  $12 \text{ Hz} / 18 \text{ Hz} = 0.67 \text{ Hz}$ . In the periodic face-like stimulation sequence, face stimuli were randomly embedded in the sequence, and face-like stimuli were presented with a period of  $12 \text{ Hz} / 18 \text{ Hz} = 0.67 \text{ Hz}$  as well as periodic face stimulation sequence. Each stimulus sequence included 60 face stimuli and 60 face-like stimuli and was presented once with stimuli upright and once with stimuli inverted. Each task condition was repeated 2 times, resulting in a total of 16 stimulation sequences (90 s each with 10 oddballs: fixation color and gender-change events; total testing time =20–30 min, including breaks). The two tasks were presented in an alternating order, and the starting condition was counterbalanced across participants. There was no order effects in either the behavioral performance or the EEG signals.

### 3.2.4 EEG-recording

The EEG was recorded using a BioSemi ActiveTwo system with 128 Ag-AgCl Active-electrodes, arranged in the default BioSemi configuration, which centers around nine standard 10–20 locations on the primary axes (BioSemi B.V., Amsterdam, Netherlands; for exact position coordinates, see <http://www.biosemi.com/headcap.htm>). Electrode labels were changed to closely match a more conventional 10–20 system (for exact relabeling, see [17]). The magnitude of the offset of all electrodes, referenced to the common mode sense (CMS), was held below 50 mV. Electrooculography (EOG) was recorded from additional channels (the infraorbital region of the right eye and the outer canthus of the right and left eye). The EEG and EOG were digitized at a sampling rate of 512 Hz.

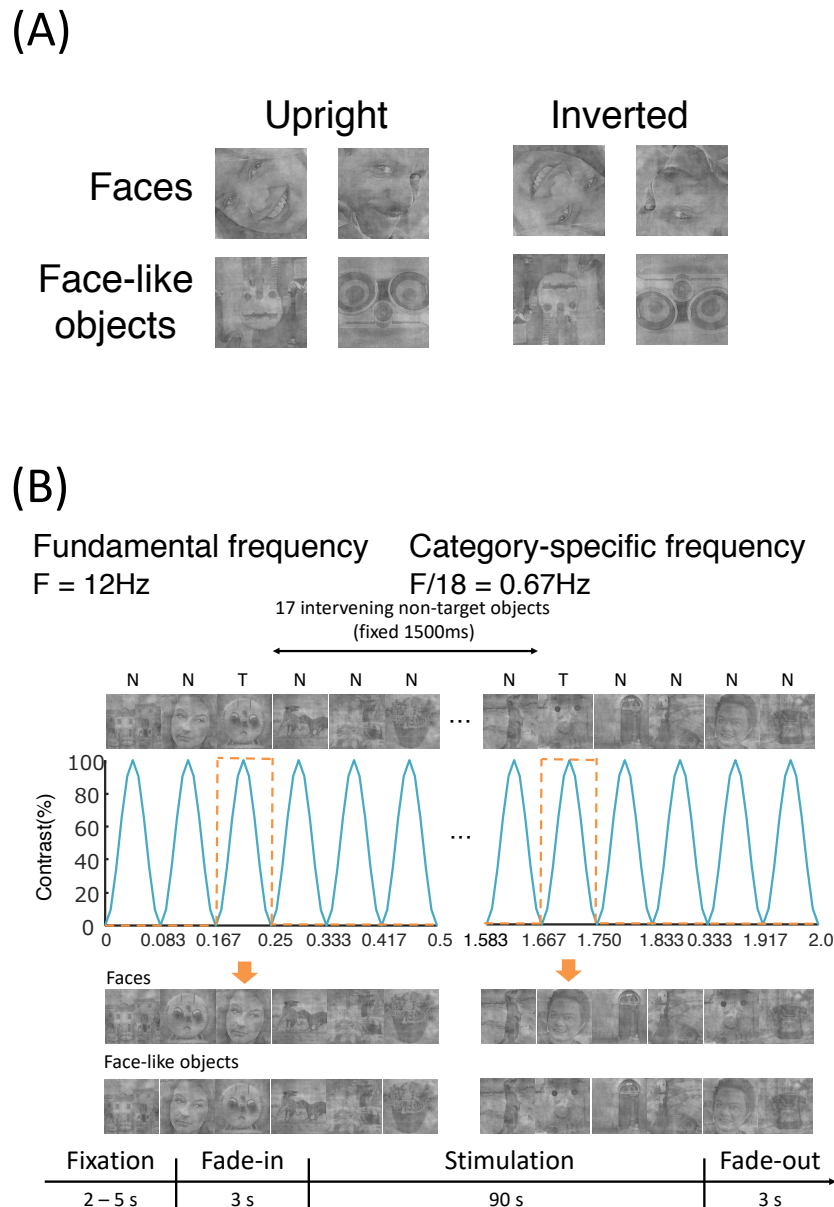


Figure 3.1: Fast periodic visual stimulation (FPVS) paradigm. (A). Examples of natural images of faces, face-like objects, animals, and houses/buildings used in the experiment. (B). Images were presented by sinusoidal contrast modulation at a rate of 12 stimuli per second (12 Hz). Stimuli were randomly selected from a large pool of images of various man-made and natural (living and non-living) objects, and different images of either faces or face-like objects (as illustrated here) were presented every 18 stimuli (i.e., appearing at the frequency of  $12\text{ Hz}/18 = 0.67\text{ Hz}$ ). In the examples of 12 Hz cycles for the two experimental conditions, images of either faces or face-like objects were used as category-specific stimuli in different sequences. The bottom shows the timeline of a whole stimulation sequence, which starts with a fixation cross displayed on a gray background for 2 to 5 s (random duration), followed by a 90 s sequence of image presentation. The image presentation sequence started by a 3-s face-in period and ended with a 3-s fade-out period.



### 3.2.5 Analysis

#### Behavioral analysis

Response time (RT) for tasks related to faces was calculated relative to the start of the target face. For the task not related to the face, the RT was calculated relative to the start of the fixation cross color change, and the average of the RTs was performed for each correct response. A response was considered correct if it occurred between 150 and 3000 milliseconds after the start of the target. Since our current paradigm did not enable the separation of mistake and false alarms, the keypress recorded outside this period was labeled as incorrect. We compared overall response accuracy, correct response time, and the number of incorrect keypresses across conditions using repeated ANOVAs with task (Face-relevant vs. Face-irrelevant), category (faces and face-like objects), and orientation (upright vs. inverted) as within-subject factors.

#### Preprocessing

Recorded EEG was analyzed using EEGLAB [61] and Fieldtrip [105] in MATLAB R2017b (MathWorks, USA). The continuously recorded data were first bandpass filtered at 0.1 to 100Hz (Butterworth filter, fourth-order) and then downsampled to 256Hz to reduce the file size and processing time. A Fast Fourier Transform (FFT) multi-notch filter with a width of 0.5 Hz was used to remove electrical noise at three harmonics of 60 Hz. They were cropped into 93s-segments for each sequence (1s before the fade-in and 0.5s after the fade-out). To remove a single component accounting for blink artifacts, independent component analysis (ICA) was applied for the data of two participants who blinked more than 0.2 times/s (mean = 0.10, SD = 0.116) during the sequences. Channels, which were artifact-prone across multiple trials (less than 1% of channels on average), were interpolated. Finally, all EEG channels were referenced to a common average.

#### Frequency-domain analysis

Following preprocessing, each sequence epoch containing a cycle of integer number of face/face-like stimulus frequency (0.67 Hz) was segmented to create an 88.51-second epoch containing exactly 59 face/face-like stimuli presentation cycles for each stimulus sequence. This process ensured that a single frequency bin in the center of the category-selective frequency (0.67 Hz) is the target of the EEG spectrum. The two epochs for each condition were averaged before applying a Fast Fourier Transform (FFT) to extract the normalized amplitude spectrum for each channel ranging from 0 to 256 Hz. The frequency resolution of these spectra was very high,

as determined by the inverse of the sequence duration (i.e.,  $1/88.5 = 0.0113$  Hz). Using the amplitude spectrum pooled across all participants, conditions, and scalp channels to identify important response signals at the relevant stimulation frequencies (i.e., 12 Hz, 0.67 Hz, and harmonics), we computed a z-score at each discrete frequency bin [101] [106] [17] [81] [83]. The average amplitude of this noise range was subtracted from the amplitude of the target frequency, and the result was divided by the standard deviation of the noise range amplitude. The advantage of determining statistical significance in this way is that unlike t-test (which depends on inter-individual variance), z-scores can be calculated at the group level or for each participant [107]. The z-scores at a given frequency were calculated by subtracting the mean amplitude of 20 neighboring frequency bins (10 bins on each side) from that frequency, divided by the standard deviation of the 20 neighboring bins. The neighboring bins did not include the two immediately adjacent frequency bins [81] [108] [101]. As shown in previous studies, response signals with z-scores greater than 3.1 were considered significant ( $p < 0.01$ , one-tailed, i.e., signal  $>$  noise). The goal was to identify frequencies where the signal is significantly larger than the noise in the surrounding bins; therefore, the use of a one-tailed test is well justified in this context. To account for noise variation across the EEG spectrum, a local baseline subtraction was performed on the raw amplitude of each condition using the same baseline range as used in the z-score calculation. Then, the baseline-corrected amplitudes were summed at the frequency harmonics of interest. The category-selective response was quantified as the sum of the seven harmonics of 0.67 Hz (0.67 Hz, 2 Hz, 2.67 Hz, 3.33 Hz, 4 Hz, 5.33 Hz, and 6 Hz), while the common response was quantified as the sum of the first three harmonics of 12 Hz (12 Hz, 24 Hz, and 36 Hz) for validation of the quantification procedure through summation of amplitudes across harmonics. When category-selective responses or common responses are mentioned, please refer to these summed and baseline-corrected responses in the following sections.

To consider noise variations across the EEG spectrum, a local corrected baseline was obtained based on the raw amplitude of each condition using the same baseline range as used in the Z-score calculation (see above). To quantify the category-selective response, baseline correction amplitudes for all relevant harmonics were summed in two ways [81] [83] at the global level by pooling information across 1) all scalp channels, and 2) functional regions-of-interest (ROIs) compatible with stable bilateral occipitotemporal patterns induced by FPVS paradigm [17] [81] [83]. The ROIs were defined by averaging the five-channel of each hemisphere: left occipitotemporal ROI (average over channels P7, P9, PO7, PO9, and PO11) and right occipitotemporal ROI (average over channels P8, P10, PO8, PO10, and PO12). The occipitoparietal ROI showed the common response at 12 Hz, averaged over 12 channels (OI1, O1, POO5, PO3h,

POz, POOz, Oz, OI2, O2, POO6, and PO4h).

## 3.3 Results

### 3.3.1 Behavior

We investigated behavioral performances across the two task conditions (Figure 3.2). There were main effects of each factor in accuracy: task [ $F(1, 15) = 7.692, p = 0.014, \eta^2 = 0.339$ ], orientation [ $F(1, 15) = 9.824, p = 0.007, \eta^2 = 0.396$ ], and condition [ $F(1, 15) = 16.653, p = 0.001, \eta^2 = 0.526$ ]. Furthermore, the following interactions were found: task  $\times$  condition [ $F(1, 15) = 9.887, p = 0.007, \eta^2 = 0.397$ ], and orientation  $\times$  condition [ $F(1, 15) = 7.843, p = 0.013, \eta^2 = 0.343$ ]. In the interaction between tasks, the accuracy in the face and the face-like condition was showed a significant difference between tasks (face:  $p < 0.001, \eta^2 = 0.62$  and face-likeness:  $p < 0.001, \eta^2 = 0.82$ ). Furthermore, in the relevant task, the accuracy in the face condition was higher than in the face-like condition ( $p < 0.001, \eta^2 = 0.21$ ). In the interaction between task and condition, the accuracies in the upright and inverted condition were showed a significant difference between tasks (upright:  $p < 0.001, \eta^2 = 0.81$  and inverted:  $p < 0.001, \eta^2 = 0.63$ ). Moreover, in the relevant task, the accuracy was higher in upright orientation than in inverted orientation ( $p < 0.005, \eta^2 = 0.21$ ).

Participants were significantly slower when responding in the face-relevant task than in the face irrelevant task [ $F(1, 15) = 1538.361, p < 0.001, \eta^2 = 0.904$ ]. In addition, participants made more incorrect keypresses in the face-relevant task than in the face-irrelevant task [ $F(1, 15) = 122.095, p < 0.001, \eta^2 = 0.611$ ].

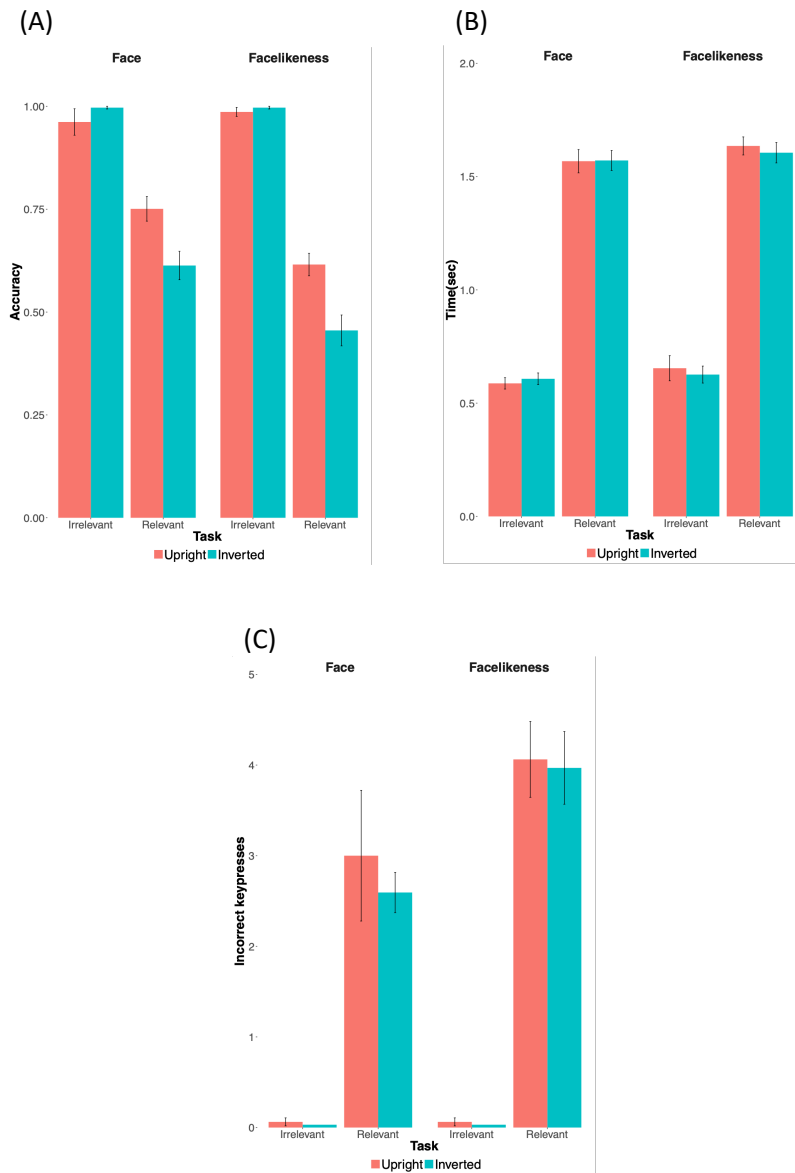


Figure 3.2: (A) Accuracy: Each bar indicates the mean accuracy for each condition in the upright and inverted orientations. (B) Response Time: Each bar indicates the mean reaction time for each condition in the upright and inverted orientations. (C) Incorrect keypresses: Each bar indicates the mean number of incorrect keypresses for each condition in the upright and inverted orientations.

### 3.3.2 Frequency-domain

#### The common response(12Hz)

The fundamental frequency rate response, which simply reflects the contrast between the background and face stimuli, is a mix of low-level and high-level processes [109], and this response is not expected to differ between conditions and tasks. As shown in previous studies using this paradigm [101] [100], the 12 Hz response was characterized by a medial occipital topography peaking at Oz for the response at the fundamental frequency rate (see Figure 3.3, 3.4). In the case of an upright face, at the fundamental frequency (12 Hz), the activity spreads specifically to the outer occipital region of the right hemisphere. To investigate the effects of orientation (inverted or upright), condition (face or face-likeness), and task (face-relevant or face-irrelevant), we defined regions of interest based on 12 electrodes. We compared the baseline-corrected amplitudes summed for the three harmonics of the base rate (Figure 3.5). Repeated measurement ANOVA for orientation (inverted or upright), condition (face or face-likeness), and task (face-relevant or face-irrelevant) revealed the main effects of task [ $F(1, 15) = 7.968, p = 0.013, \eta^2 = 0.018$ ], with an average of 26% increase in response to the face-relevant task as compared with the face-irrelevant task.

In summary, we observed larger responses to face-relevant than to face-irrelevant tasks at the base stimulation rate, and this difference was non-significant over medial occipital sites where responses to low-level stimuli were typically recorded.

#### The category-selective response(0.67Hz)

As previously reported for category-selective responses, the EEG spectrum showed a high SNR response (which reflects the detection of face detection) at 0.67 Hz for harmonics in the face-relevant task (Figure 3.3, 3.4). The response was much larger for upright faces than for inverted faces over occipitotemporal sites, and the discrimination responses were barely visible when faces were presented upside-down. The magnitudes of the inversion effect [(upright-inverted)/inverted] for each condition averaged across tasks and two occipitotemporal ROIs reached 257% and -89% for the face condition and the face-like condition, respectively. This finding indicates that the inversion has a strong effect on perception. Furthermore, the magnitude of the task modulation effect [(face-relevant - face-irrelevant)/face-irrelevant] was calculated in the same way as above described. The face condition and face-like condition reached 798% and -122%, respectively, indicating that the task has a strong modulation on perception.

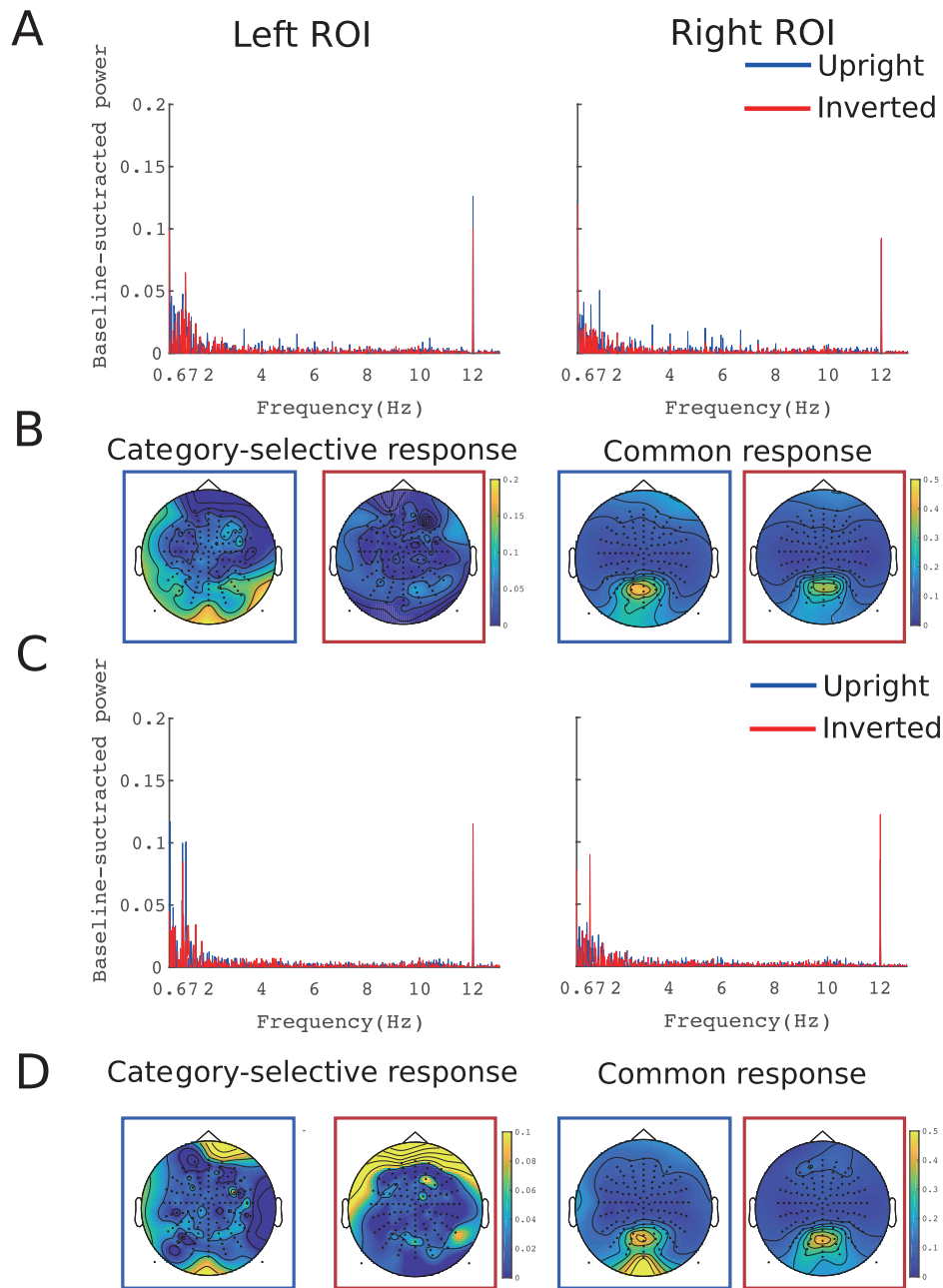


Figure 3.3: (A). Baseline-subtracted amplitude spectra at the left and right pooled occipitotemporal electrode sites (averaged for channels P7/P9/PO7/PO9/PO11 and P8/P10/PO8/PO10/PO12) in the face condition for the face-irrelevant task. (B). 2-D scalp topographies in the face condition show category-specific responses (right side) and common frequency responses (left side). (C). Baseline-subtracted amplitude spectra at the left and right pooled occipitotemporal electrode sites (averaged for channels P7/P9/PO7/PO9/PO11 and P8/P10/PO8/PO10/PO12) in the face-like condition for the face-irrelevant task. (D). 2-D scalp topographies in the face-like condition show category-specific responses (right side) and common frequency responses (left side).

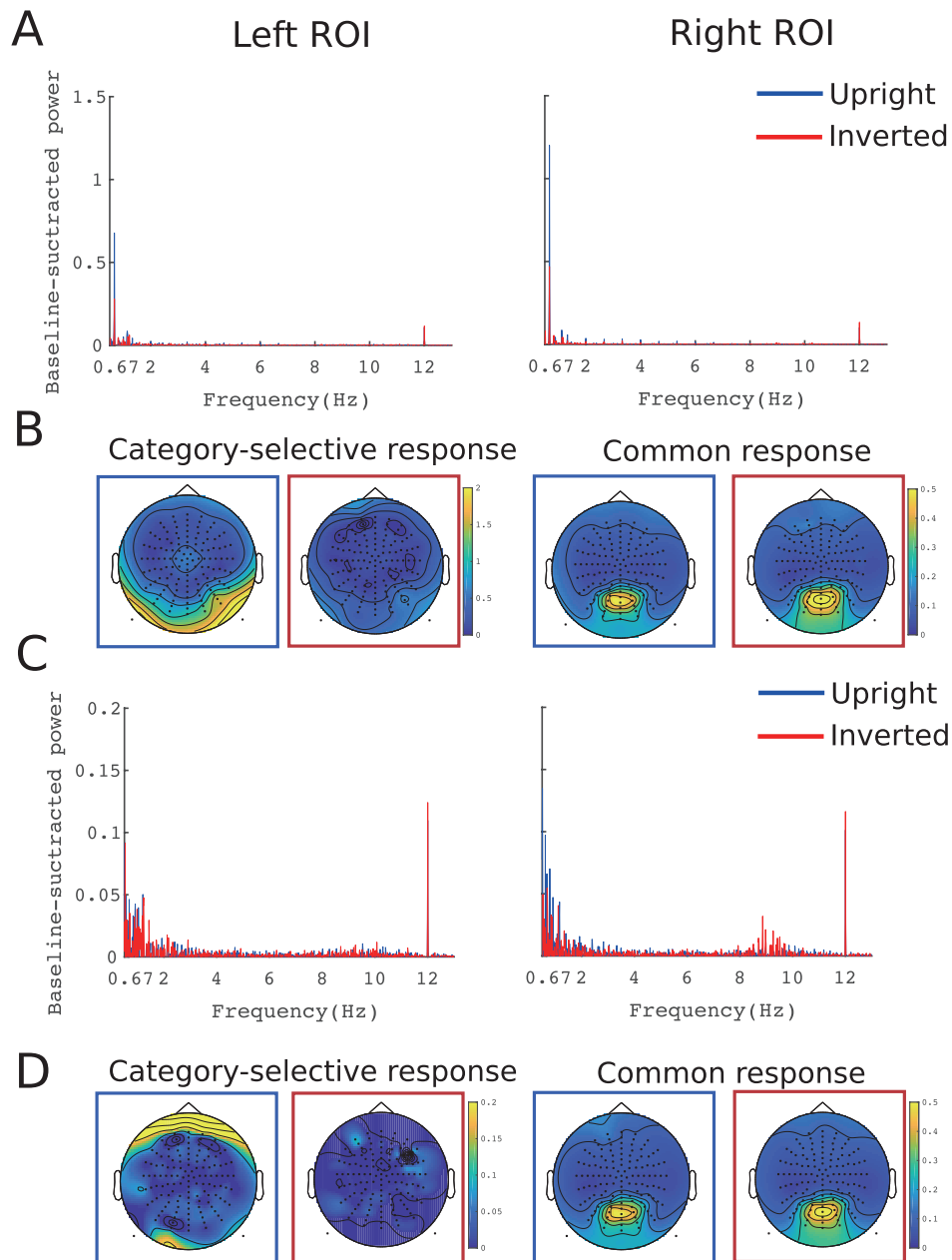


Figure 3.4: (A). Baseline-subtracted amplitude spectra at the left and right pooled occipitotemporal electrode sites (averaged for channels P7/P9/PO7/PO9/PO11 and P8/P10/PO8/PO10/PO12) in the face condition for the face-relevant task. (B). 2-D scalp topographies in the face condition show category-specific responses (right side) and common frequency responses (left side). (C). Baseline-subtracted amplitude spectra at the left and right pooled occipitotemporal electrode sites (averaged for channels P7/P9/PO7/PO9/PO11 and P8/P10/PO8/PO10/PO12) in the face-like condition for the face-irrelevant task. (D). 2-D scalp topographies in the face-like condition show category-specific responses (right side) and common frequency responses (left side).

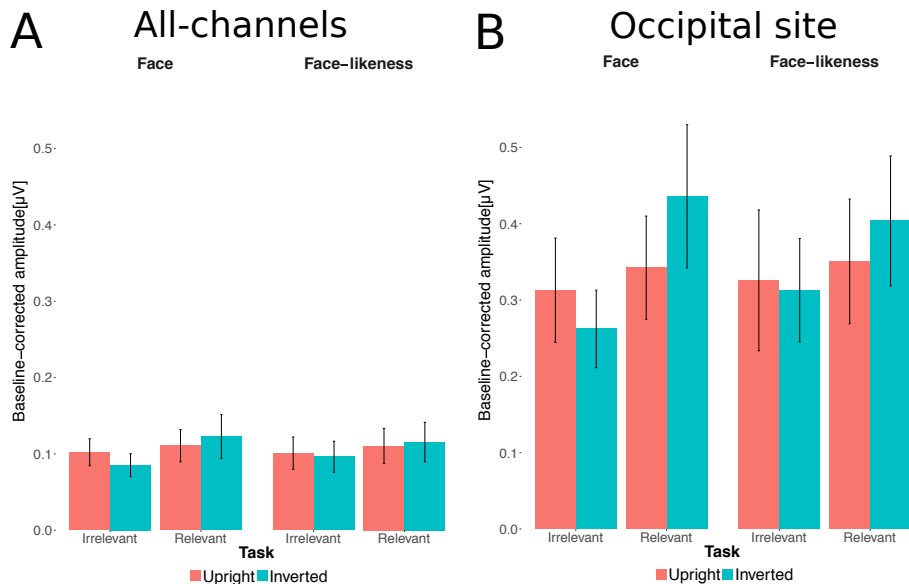


Figure 3.5: Sum of baseline-corrected amplitudes representing the common response

**Responses over the whole scalp** The grand-averaged summed baseline-corrected amplitudes at each condition, each orientation, and tasks were pooled over all channels (see Figure 3.6 A). A repeated-measures ANOVA on the responses across the whole scalp with Orientation (Upright, Inverted), Condition (Face, Face-likeness), and Task (Face-relevant, Face-irrelevant) as within-subject factors revealed no main effect or interaction.

**ROI analysis** Right region of interest (Figure 3.6 B): a three-way repeated ANOVA with Condition (Face or Face-likeness), Orientation (Upright or Inverted) and Task (Face-relevant or Face-irrelevant) as within-subjects factors was used to analyze the category-selective responses. The results showed significant main effects of each factors Task [ $F(1, 15) = 7.775, p = 0.014, \eta^2 = 0.069$ ], Orientation [ $F(1, 15) = 7.48, p = 0.015, \eta^2 = 0.021$ ], and Condition [ $F(1, 15) = 12.829, p = 0.003, \eta^2 = 0.099$ ], and also a significant interactions of Task  $\times$  Orientation [ $F(1, 15) = 4.677, p = 0.047, \eta^2 = 0.017$ ], Task  $\times$  Condition [ $F(1, 15) = 9.002, p = 0.009, \eta^2 = 0.076$ ], and Orientation  $\times$  Condition [ $F(1, 15) = 5.863, p = 0.029, \eta^2 = 0.017$ ]. Further analyses showed that for both tasks, the responses were larger in the Face condition than in the Face-likeness condition (Face-relevant: [ $t(1, 15) = 10.841, p = 0.005, \eta^2 = 0.19$ ]; Face-irrelevant: [ $t(1, 15) = 8.374, p = 0.011, \eta^2 = 0.089$ ]). Moreover, for the face condition, the responses were larger in the Face-relevant task than that in the Face-irrelevant task [ $t(1, 15) = 8.404, p = 0.011, \eta^2 = 0.163$ ]. Regarding the significant interaction of Task  $\times$  Orientation, further analyses showed that the responses were larger in the Face-relevant task than in the



Face-irrelevant task for both orientation (Inverted:  $[t(1, 15) = 7.693, p = 0.014, \eta^2 = 0.085]$ ; Upright:  $[t(1, 15) = 6.796, p = 0.02, \eta^2 = 0.089]$ ). Moreover, for the Face-relevant task, the responses were larger in the Upright orientation than in Inverted orientation  $[t(1, 15) = 6.052, p = 0.027, \eta^2 = 0.041]$ . Regarding the significant interaction of Condition  $\times$  Orientation, further analyses showed that the responses were larger in the Face condition than in the Face-like condition for both orientations (Inverted:  $[t(1, 15) = 18.336, p = 0.001, \eta^2 = 0.167]$ ; Upright:  $[t(1, 15) = 10.243, p = 0.006, \eta^2 = 0.112]$ ). Moreover, for the Face condition, the responses were larger in the Upright orientation than in the Inverted orientation  $[t(1, 15) = 6.77, p = 0.02, \eta^2 = 0.042]$ .

Left region of interest (Figure 3.6 B): a three-way repeated ANOVA with Condition (Face or Face-likeness), Orientation (Upright or Inverted) and Task (Face-relevant or Face-irrelevant) as within-subjects factors was used to analyze the category-selective responses. The results showed significant main effects of each factor (Task  $[F(1, 15) = 7.049, p = 0.018, \eta^2 = 0.059]$ , and Condition  $[F(1, 15) = 11.977, p = 0.003, \eta^2 = 0.087]$ ) and also a significant interaction of Task  $\times$  Condition  $[F(1, 15) = 7.854, p = 0.013, \eta^2 = 0.053]$ . Further analyses showed that for both tasks, the responses were larger in the Face condition than in the Face-likeness condition (Face-relevant:  $[t(1, 15) = 10.012, p = 0.006, \eta^2 = 0.151]$ ; Face-irrelevant:  $[t(1, 15) = 8.969, p = 0.009, \eta^2 = 0.098]$ ). Moreover, for the face condition, the responses were larger in the Face-relevant task than that in the Face-irrelevant task  $[t(1, 15) = 7.502, p = 0.015, \eta^2 = 0.125]$ .

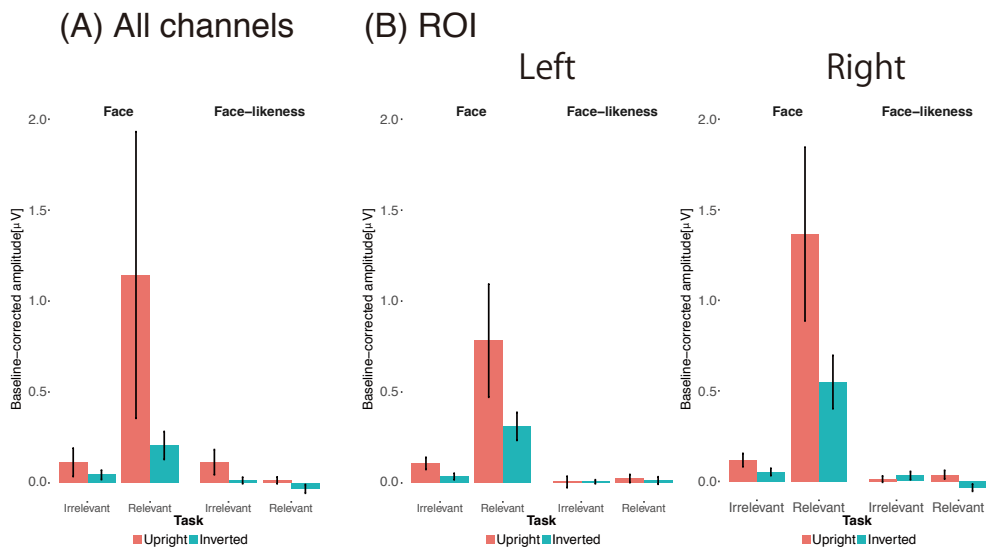


Figure 3.6: Sum of baseline-corrected amplitudes representing the selective responses.

## 3.4 Discussion

We investigated how a face-relevant task (i.e., searching for a specific face gender) modulates neural responses reflecting rapid face-likeness detection, measured with FPVS-EEG. Observers completed either a face-irrelevant task (detect rare and random color changes) or a face-relevant task (detect rare and random male/female faces among sequences of male/female faces). Participants completed the face-irrelevant task with  $> 95\%$  accuracy and the face-relevant task with  $> 65\%$  accuracy. The accuracy of the face-relevant task was lower because the presentation frequency was high and it was difficult to recognize the stimulus.

### 3.4.1 Frequency domain

The briefly presented natural images of the faces generate a large electrophysiological response in the right occipitotemporal cortex, as demonstrated in a recent study [17]. Since this response reflects the distinction of the face from other objects (living and non-living) and generalization of the whole face, the low-level contribution (e.g., the face size, viewpoint, and direction) does not affect the face-selective response. In this study, we investigated the face-likeness selectivity response by replacing the face image of the sequence with a face-like category associated with the face. Furthermore, we examined how the response changes depend on the attentional state of the sequence (task difference).

Importantly, the category-specific stimulus frequency and its harmonics (0.67 Hz and  $n \cdot 0.67$  Hz) are not absolute responses to the face or face-likeness, but the responses to each of these categories are different compared with those to numerous object categories. The brain response common to other objects, which is a mixture of low- and high-level visual processes, is projected to the fundamental stimulus presentation rate and its harmonics (12 Hz and  $n \cdot 12$  Hz). The response at  $n \cdot 0.67$  Hz was previously assumed to be unique to the face appearing at a frequency but may have been at least partially observed with face-like stimuli appearing in every 17 images of the rapid stimulus stream [102] [85] [17]. However, the results of the present study showed that the responses observed for face-like objects in the FPVS stream did not show category selectivity. The present study indicates that the response truly reflects the selectivity for the face.

We replicated the previous results by finding the individual's face discrimination response for the face condition in the EEG frequency domain on the occipitotemporal channel, dominated by the right hemisphere (e.g., [100] [101] [110] [111]). These findings further confirm FPVS-EEG as a robust neurofunctional method for examining high-level perceptual processing

with high objectivity and sensitivity. More importantly, our data indicate that tasks significantly modulate the neural responses elicited by changes in facial identity. Discrimination gender increased this response even in both occipital regions (up to 798% amplitude increase in both right and left hemispheres). These observations are consistent with those in previous studies, which indicate that selective attention can enhance face processing [91] [90] [93] [97]. Furthermore, importantly, the face-relevant task for the face condition increased the overall amplitude of the response across the scalp and indeed reduced the relative spatial selectivity of the neural discrimination response. In fact, it was found that the face-relevant task for the face condition elicited a relatively strong increase in activity in the occipital region. These observations suggest that focusing directly on the face enhances neural face discrimination by employing additional processes that are not normally automatically associated with special face processing. Thus, in the orthogonal fixation task (the face-irrelevant task), the neural discrimination response is driven primarily by specialized face discrimination processing and reflects individual face identification, while the explicit face task response appears to contain a greater mixture of processes.

On the other hand, we could not observe the face-like discrimination response for both face-irrelevant and face-relevant task conditions in the EEG frequency domain on the occipitotemporal channel, dominated by both right and left hemispheres. However, the category-selective response was observed more intensely, but not significantly, in the occipital region than in other regions, suggesting that face-likeness is detected in the primary visual processing. In the face-irrelevant task, it is predicted that the category-specific response will not be observed because the attention is not paid to the face-like object, and the ambiguous objects are not perceived as a face. In addition, it is possible that the face-likeness is automatically detected from face-like objects by primary visual processing; therefore, the category-selective response might be observed even under the face-irrelevant task. However, our results indicate that these predictions are incorrect. Since the face-like patterns used in this experiment have various categories, the discrimination process with other non-face objects is relatively low, and the generalization process is also low. Therefore, the category-selective response observation is difficult.

Furthermore, in the face-relevant task, the discrimination gender decreased this response even in both occipital regions (up to -122% amplitude decrease in both the right and left hemispheres). Several possible reasons are as follows: The face processing was extended by selective attention, and the detection of ambiguous patterns as faces was suppressed; accordingly, the effect of reducing category-selective responses was observed. In other words, our findings suggest that the detection of ambiguous information such as face-likeness is suppressed when performing high-precision face identification in a visual processing system.

### 3.4.2 Conclusions

The present study used the human brain's synchronization to periodic visual input to investigate how face-likeness detection and discrimination are modulated by a face-relevant task. Results showed that the visual system discriminated individual faces automatically and rapidly in the absence of the explicit attention to faces, but not face-like objects.

Although a face-relevant task substantially increased the individual face discrimination response over occipitotemporal regions in the face condition, it also reduced the response in the face-like condition by suppression of the detection of ambiguous patterns such as faces. The visual system may have a cognitive mechanism discriminating actual faces from face-like objects.

## Chapter 4

# Pupillary response to face pareidolia

### 4.1 Introduction

The basic cognitive mechanism of the pareidolia phenomenon is considered to be based on the face perception processing mechanism. Humans see an object and unconsciously judge whether it is a human face or not. This ability to recognize the face is a high-level perception function of humans. In face perception, our brain conducts two processing: featural processing that recognizes from facial elements such as “eyes, nose, and mouth” and holistic processing that recognizes from the arrangement of the facial elements. In particular, holistic processing is related to the pareidolia phenomenon [12].

For this reason, this phenomenon was considered a relatively low-level cognitive process. However, recently, it has been thought that this phenomenon is due to the high-level cognitive process that occurs due to the influence of the top-down process. Liu et al. demonstrated that the pareidolia phenomenon occurs even when random noise images without facial features are used, and the occipital region associated with face perception and prefrontal cortex activity is related to high-level cognitive functions such as executive function. The findings suggest that this phenomenon is influenced by the Top-down process [13].

To date, a few studies have measured the response of the cortical pathway and elucidated the mechanism of this phenomenon. However, no studies have investigated whether the processing of this phenomenon contributes to bottom-up and top-down processing. Therefore, in this study, we investigated the contribution of the bottom-up and top-down processing to the pareidolia phenomenon using the pupil diameter response. Conventionally, the pupil diameter response reflects high-level perception, such as preference and interest, and is considered to be influenced by high-level perception [112] [113]. However, recently, it has been suggested that

the pupillary response reflects low-level visual processing, and small and fast pupil constriction can be observed for stimuli with complex visual features [114] [115] [116]. When an emotional facial stimulus is presented, the response of the autonomic nervous system is reflected, and the pupil dilation occurs [117] [118]. Recently, pupillary responses related to face perception have been examined [119], and these pupillary responses respond to inverted faces and macaque faces.

For this reason, the pupillary response to face-likeness should be expected. Accordingly, not only the bottom-up processing but also the top-down processing (high-level perception) can be observed using the pupillary response. If the bottom-up processing contributes to the face pareidolia phenomenon, it is expected that the pupillary response is the same as the response when the face is perceived even if a task unrelated to the face is performed for a stimulus perceived as a face. On the other hand, if the top-down processing greatly contributes to the face pareidolia phenomenon, it is predicted that a change in the pupillary response is observed only when the task related to the face is performed. In this study, we investigated the contribution of bottom-up and top-down processing to the face pareidolia phenomenon using the pupillary response.

## 4.2 Materials and methods

### 4.2.1 Participants

Thirteen healthy, right-handed volunteers (age: 23–25 years, 1 female) with normal or corrected-to-normal vision participated in the experiment. Informed written consent was obtained from participants after procedural details had been explained. The Committee for Human Research of Toyohashi University of Technology approved the experimental procedures.

### 4.2.2 Stimuli

The stimuli consist of circles with a size of  $5.00^\circ \times 5.00^\circ$  as a face outline (hereinafter referred to as "Outline circle") and small black circles with a size of  $1.25^\circ \times 1.25^\circ$  imitating facial part of eyes, nose, and mouth (hereinafter referred to as "Parts circle"). In this study, the stimulus type was defined by the arrangement of facial parts' circles, and symmetry was defined as line symmetry, not centrosymmetry. Four stimulus types are defined below: HH stimulus type (high face-likeness, high symmetry), Y-shaped arrangement with the center of the outline circle as the axis; LH stimulus type (low face-likeness, high symmetry), arranged like a square; LL stimulus

type (low face-likeness, low symmetry), trapezoidal arrangement; HL stimulus type (high face-likeness, low symmetry), Y-shaped arrangement with the shifted position from the center of the outline circle. Figure 4.1 shows how to arrange each stimulus type. For the HH stimulus type, the distance between the small circles imitating the left and right eyes was changed around the small circle imitating the nose (1, 2, 3, and 4 degrees), the distance between the small circle imitating the mouth and nose was also changed (1, 2, 3, and 4 degrees), and a variety of above stimuli ( $4 \times 4 = 16$  stimuli) were combined. Similarly, the LH and LL stimulus types were combined with different short side and long side distances, and a total of 16 stimuli were used in each stimulus type. For the HL stimulus type, the small circles arranged in the Y-shape were fixed, and they were arranged at distances of 1, 2, 3, and 4 degrees in the direction of 45, 135, 225, and 315 degrees from the center of the outline circle. A variety of the above stimuli ( $4 \times 4 = 16$ ) were combined. These stimuli were prepared upright and inverted (upside-down,  $180^\circ$  rotation), and were presented with 256 images of 4 stimulus types  $\times$  2 tasks  $\times$  2 orientations  $\times$  16 images.

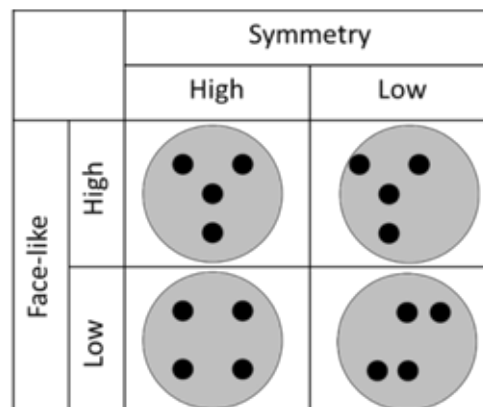


Figure 4.1: Examples of stimuli: the upper face is defined as high face-likeness, and the below face is defined as low face-likeness; the left side symmetry is high, and the right side symmetry is low.

### 4.2.3 Procedure

At the start of each trial, a fixation point appeared in the center of the screen for 1000 ms, followed by the presentation of the scrambled stimulus for 1000 ms, a target stimulus for 2000 ms, and a scramble stimulus as a mask. Participants were instructed to respond with a keyboard button response whether the presented stimulus was a face-like or non-face-like object (face-like

task) and symmetric or asymmetric (symmetric task). There were two experimental sessions for each task. In each session, 16 trials for each stimulus type were presented randomly.

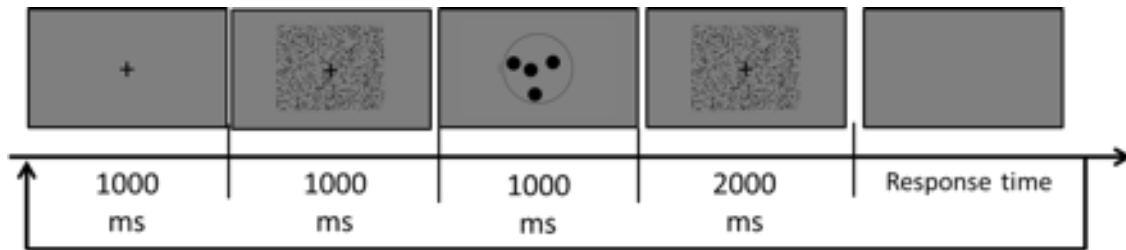


Figure 4.2: The stimulus presentation procedure in the experiment. First, the fixation cross was presented for 1 second, followed by the scrambled stimulus for 1 second. Immediately thereafter, the target stimulus was presented for 1 second. The scrambled stimulus was presented for 2 seconds after the presentation of the target stimulus. The participants then responded to the task.

#### 4.2.4 Pupillary response recording

The experiment was performed in a dark room, and the stimulus presentation was controlled by Psychtoolbox [104] and presented on an LCD monitor (VIEWpixx, Vpixx, resolution  $1920 \times 1200$  pixels, FrameRate 120 Hz). The participants viewed a computer monitor at a distance of 60 cm. The pupil diameter was measured using Eyelink 2000 (SR research system, Canada), and the data were recorded at a sampling frequency of 500 Hz.

#### 4.2.5 Analysis

The pupillary response data and behavioral data were computed for each condition. In this study, we only analyzed upright orientation because the LH and LL stimulus types during the inverted orientation were the same in the upright orientation, and a behavioral response that looked like a face was not obtained under the HH and HL stimulus types during the inverted orientation. For the pupil diameter response analysis, when the scrambled stimulus was presented, the timing of 0 ms was defined as the onset, and the interval from 500 ms to 0 ms before the scrambled stimulus was presented as the baseline. The trials with blinking were rejected, four stimulus types were included in the trials for each subject, and the average was calculated. The peak amplitude of dilation was computed using the difference from the minimum value to



the maximum value of the pupil diameter after the target stimulus presentation. Furthermore, the change in pupil diameter response during 2000 ms after the end of the target stimulus presentation was averaged and used as the mean pupil dilation amplitude.

## 4.3 Results

### 4.3.1 Behavior

Figure 4.3 shows the behavioral results. We used repeated-measures analysis of variance for two factors (task, stimulus type) to analyze the response rate in each task, and main effects were observed for each stimulus type [Stimulus types:  $F(3, 36) = 357.493, p < .0001, \eta^2 = 0.96$ ], and interaction [Tasks and Stimulus types:  $F(3, 36) = 280.823, p < .0001, \eta^2 = 0.95$ ]. The simple main effect test (Bonferroni method) for this interaction found both effects for tasks and stimulus types. The results of multiple comparisons showed that the response rate was higher in the HH and HL stimulus types than in other stimulus types ( $p < .001$ ) in the face-likeness evaluation task. The main effect of the response rate was higher than that of the stimulus type ( $p < .001$ ). Regardless of the task, the LL stimulus type had a lower response rate than any other stimulus types ( $p < .001$ ).

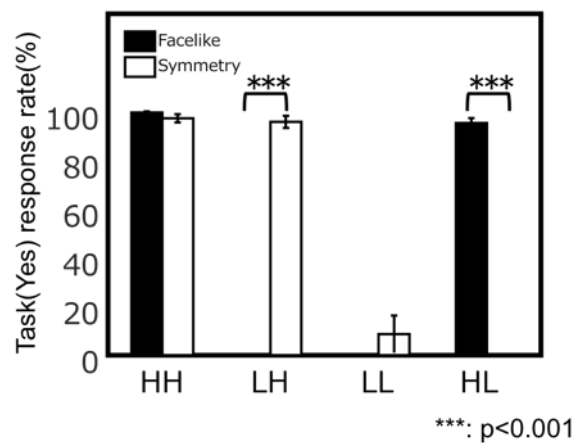


Figure 4.3: Results of behavioral analyses: The black bar indicates the task response rate (YES response) during the face-likeness evaluation task, and the white bar indicates the task response rate during the symmetry evaluation task.

### 4.3.2 Pupillary response

The results of the pupillary response are shown in Figures 4.4. The pupillary responses observed under the HH, LL, and LH stimulus types did not differ between tasks. However, in the HL stimulus type, there were difference between the tasks in the pupil dilation peak amplitude and the pupil dilation amount after the stimulus presentation. Therefore, the pupil dilation peak amplitude and the pupil dilation amount under each stimulus type were calculated and compared.

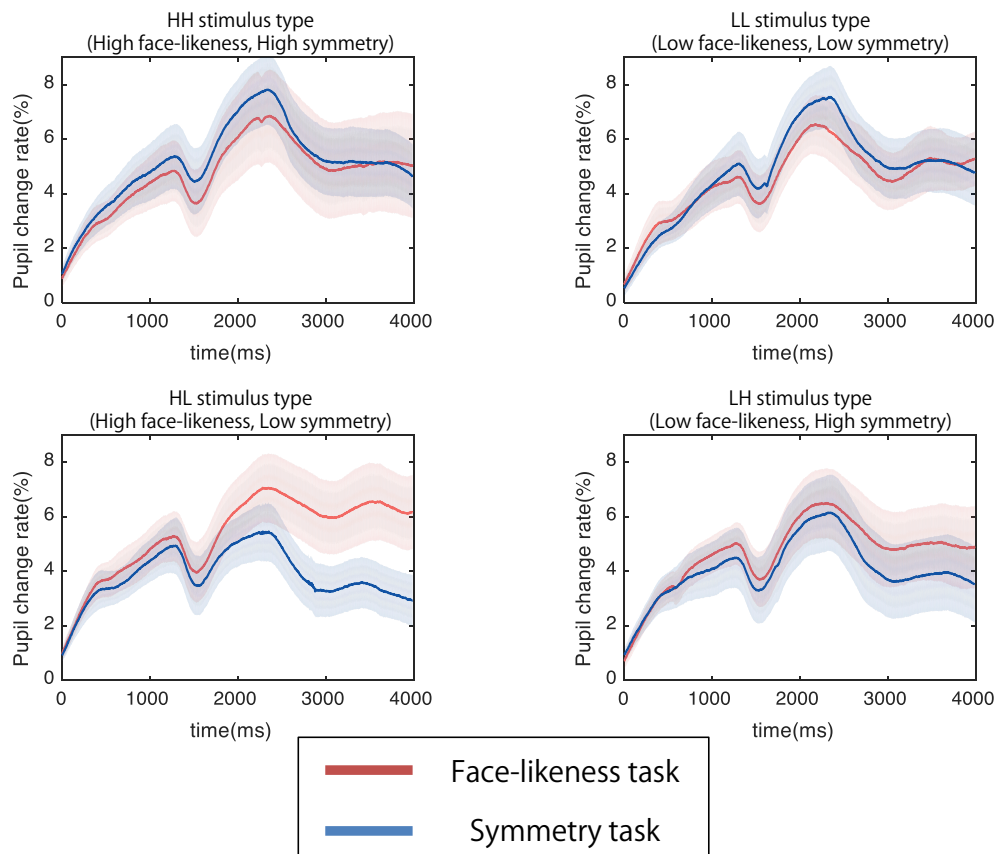


Figure 4.4: The pupil diameter response of each stimulus type at each task. The red line shows the pupil diameter response in the face-likeness evaluation task, and the blue line shows the pupil diameter response in the symmetry evaluation task. The shaded line of each line shows the standard error between subjects.

### Dilation peak amplitude

Since it was difficult to compare each stimulus type from the pupillary response (Figure 4.4), the pupil dilation peak amplitude for each stimulus type was calculated for comparison in each stimulus type. Figure 4.5 A shows the calculated pupil dilation peak amplitude. Two-factor (task, stimulus type) repeated measurement ANOVA was used to analyze the calculated pupil dilation peak amplitude. ANOVA showed the interaction between tasks and stimulus types [ $F(3, 36) = 2.948, p = 0.045, \eta^2 = 0.19$ ]. The simple main effect test (Bonferroni method) for this interaction showed a significant difference trend in the task effect for the HL stimulus type [ $F(1, 12) = 3.692, p = 0.079, \eta^2 = 0.23$ ]. In addition, the stimulus types showed a main effect in the symmetry evaluation task [ $F(3, 36) = 3.884, p = 0.016, \eta^2 = 0.25$ ]. Multiple comparisons showed that the increase in pupil dilation was significantly lower in the HL stimulus type than in the LL stimulus type ( $p < 0.05$ ).

### Dilation peak difference

Figure 4.5 B shows the pupil dilation peak amplitude difference between tasks based on each stimulus type. The amplitude difference between tasks was larger in the HL stimulus type than in other stimulus types. One-way repeated measure ANOVA was used to analyze the calculated peak amplitude difference between tasks, and there was a significant effect [ $F(3, 36) = 2.993, p = 0.0435, \eta^2 = 0.19$ ].

Multiple comparisons found a significant difference tendency in the HL stimulus type, and the amplitude difference between tasks was larger in the HL stimulus type than in the HH stimulus type ( $p < 0.1$ ).

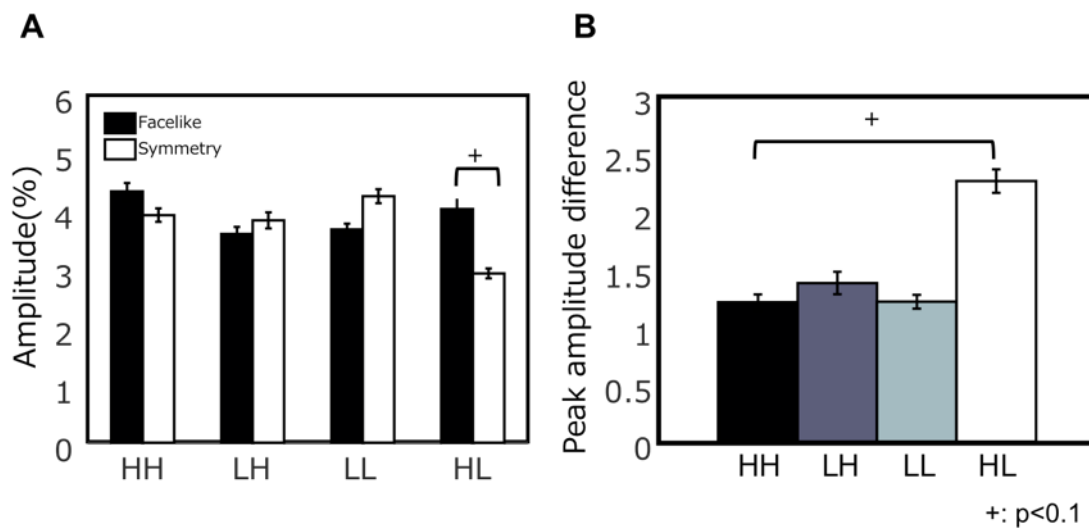


Figure 4.5: A) Peak amplitudes of the pupil dilation at each task. The black bar indicates the peak amplitude value during the face-likeness evaluation task, and the white bar indicates the peak amplitude value during the symmetry evaluation task. The error bar shows the standard error between subjects. B) the absolute difference between the peak amplitude value during the face-likeness evaluation task and the peak amplitude value during the symmetry evaluation task. The black bar indicates the HH stimulus type, the dark gray bar indicates the LH stimulus type, the light gray bar indicates the LL stimulus type, and the white bar indicates the HL stimulus type.

### Constriction peak amplitude

Differences in the pupil constriction peak amplitudes between tasks were compared between stimulus types. Two-factor repeated ANOVA (task, stimulus type) was used to analyze the calculated peak amplitude, and all factors had no significant effect.

### Mean pupil dilation amplitudes after stimulus presentation

The dilation amount of the pupillary response for two seconds after the stimulus presentation was averaged in each stimulus type. Figure 4.6 shows the average pupil dilation amount in each stimulus type. Two-way repeated measure ANOVA was used to analyze the calculated average pupil dilation amount, and interaction between tasks and stimulus types was observed [ $F(3, 36) = 2.265, p = 0.0975, \eta^2 = 0.16$ ]. The simple main effect test (Bonferroni method) for this interaction showed a significant tendency in task effects in the HL stimulus type [ $F(1, 12) = 3.255, p = 0.096, \eta^2 = 0.21$ ].

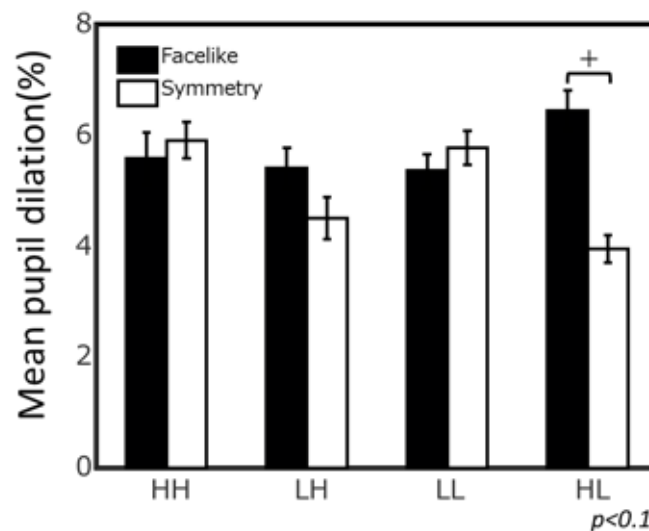


Figure 4.6: The black bar indicates the average pupil dilation response during the face-likeness evaluation task, and the white bar indicates the average pupil dilation response during the symmetry evaluation task.

## 4.4 Discussion

The purpose of this study was to observe the effects of bottom-up and top-down processing on the pareidolia phenomenon. We compared the pupillary responses between two different tasks when face-like stimuli were presented. Large pupil dilation was observed for the face-like stimulus only in the face-likeness evaluation task, and such a pupillary response was not observed in the symmetrical evaluation task. Therefore, in the pupillary response, the effect of top-down processing on pareidolia was observed, but that of bottom-up processing was not.

### 4.4.1 Perception in behavioral indexes

Behavioral analysis results showed that the response rate of high face-like stimuli was higher in the face-likeness evaluation task, and the response rate of high symmetrical stimuli was high in the symmetry evaluation task. Furthermore, in the face-likeness evaluation task, the stimuli of the HL stimulus type were judged to be faces; however, in the symmetry evaluation task, they were judged not to be symmetrical. Therefore, the HL stimulus type affected in the face-likeness evaluation task leads to a cognitive bias to evaluate face-likeness. The same findings were observed in the LH stimulus type. Based on the behavioral results, it is possible to observe the face-likeness perception affected by Bottom-up and Top-down processing by comparing the pupil diameter responses of HL and LH stimulus types at each task.

### 4.4.2 Dilation peak amplitude difference between conditions

Different pupillary responses have been observed for different tasks and different stimulus types. We hypothesized that the same pupillary response is observed regardless of the tasks if the bottom-up processing for the pareidolia phenomenon is affected. As shown in Figure 4.5, the HH stimulus types did not depend on the tasks, and the pupil dilation peak amplitude was high. However, Gee et al. [113] suggested that the decision made during the tasks affects the pupillary response, and the pupil dilation increases as a bias to the pupillary response to the “Yes” response of the two Alternative Forced Choice Tasks. Therefore, these biases seem to increase the pupil dilation without depending on the task.

Similarly, the pupil dilation increased due to decision-making bias in the HL stimulus type during the face-likeness evaluation task and in the LH stimulus type during the symmetry evaluation task. However, in the LL stimulus type during the symmetry evaluation task, the pupil dilation increased despite no decision-making bias; accordingly, it was unlikely that only the decision-making bias affected the pupil dilation. Thus, a bias different from the decision-

making bias occurs in the LL stimulus type during the symmetry evaluation task. On the other hand, the pupil dilation decreased in the HL stimulus type in the symmetry evaluation task under the same environment. If a bias occurs, it is expected that the pupil dilation will increase as observed in the LL stimulus type. However, such bias did not occur in the HL stimulus type, and in contrast, pupil dilation decreased. Based on these results, the effect of the bottom-up processing on the pareidolia phenomenon was not reflected in the pupil diameter response, and different pupil diameter responses were observed for different tasks and stimulus types.

The pupil dilation decreased in the HL stimulus type during the symmetry evaluation task, probably due to the suppression effect by top-down processing. Gazzaley et al. [120] suggested that the top-down effect enhances or suppresses the magnitude and speed of neural activity. Therefore, pupil dilation is reduced in the HL stimulus type during the symmetry evaluation task, and the face-likeness judgment is suppressed by the top-down effect. However, the suppression effect due to the top-down effect might occur not only in the symmetry evaluation task but also in the LH stimulus type in the face-likeness evaluation task. Nevertheless, the reduction of pupil dilation was not observed in the LH stimulus type in the face-likeness evaluation task. The findings suggest that the HL stimulus type in the symmetry evaluation task has a stronger suppression effect than the LH stimulus type during the face-likeness evaluation task. However, the suppression effect due to the top-down effect might occur not only in the symmetry evaluation task but also in the LH stimulus type in the face-likeness evaluation task. Nevertheless, the reduction of the pupil dilation was not observed in the LH stimulus type in the face-likeness evaluation task, and such suppression effect was not observed in the pupil constriction. Thus, face perception may be prioritized over other visual perceptions.

### 4.4.3 Dilation amplitude differences after stimulus onset

As shown in Figures 4.4, not only the pupil dilation peak amplitude in the HL stimulus type but also the pupil dilation response after the presentation of the stimulus showed large difference depending on the tasks. However, similar changes in the pupil dilation response were not observed in other stimulus types. Hossain and Yeasin [121] suggested that the pupil dilation is associated with cognitive load. Therefore, the pupil dilation response in the HL stimulus type is related to the cognitive load of stimuli. In other stimulus types, facial parts were placed in the center of the outline of a face; thus, the cognitive load as described above was small, and the pupil dilation responses did not change between tasks. Because this cognitive load was observed only in the face-likeness evaluation task, the difference in the pupil dilation response in the HL stimulus type is considered to be due to the effect of face perception.

#### 4.4.4 Pupillary response on pareidolia

The suppression effect was observed in the pupil dilation peak amplitude during the symmetry evaluation task. Furthermore, a difference was observed between the tasks in the pupil dilation response after stimulus presentation in the HL stimulus type. The pupil dilation has been reported to reflect the response of the sympathetic nervous system [117] [122]. Accordingly, these results suggest that the pareidolia phenomenon is associated with sympathetic responses. In addition, Bradley et al., [117] suggested that the pupil dilation is affected by the amygdala. Face perception processing has been reported in the subcortical pathway via the amygdala [10]. These results suggest that the pupil dilation response in the HL stimulus type is related to face perception processing. Moreover, it has been demonstrated that gaze cueing and visual search enhancement caused by the pareidolia phenomenon only occur when face-like stimuli are previously recognized as faces [24] [25] [23]. The difference in the pupil dilation observed in this study reflects the top-down effect in the pareidolia phenomenon.

#### 4.4.5 Conclusions

The purpose of this study was to observe the effects of bottom-up and top-down processing on the pareidolia phenomenon. We investigated the pupil diameter response when face-like stimuli were presented, and we observed that the suppression effect was induced to make it difficult to produce face perception in the symmetry evaluation. These results suggest that face-like perception is suppressed by the top-down effect in the task that does not judge face-likeness, and this suppression effect can be observed in the pupil dilation; in addition, the pareidolia phenomenon affects the pupil diameter response, and this study provides a new non-invasive measurement method for the pareidolia phenomenon.



## Chapter 5

# Face-like perception effects on preference

### 5.1 Introduction

When humans encounter a meaningful stimulus, their attention increases reflexively [123]. Sudden or unexpected reflexive reactions to important stimuli are known as orienting responses [124] [125]. This innate sensitivity results in a "reflexive response to environmental stimuli so that there is a transient orientation to the stimulus" [126]. The orienting response is not necessarily consistent with the overt behavioral response, but it "helps enhance information processing and prepares or promotes rapid action on evoked stimuli" [127]. The psychological studies have indicated that both novel and meaningful stimuli elicit orientating responses [128] [129]. Novel stimuli are unknown or unexpected stimuli, but meaningful stimuli (e.g., faces) might convey information related to the individual and possible emotion. It has been suggested that orienting responses can be induced by familiar stimuli (such as the face) that are particularly important for humans [130] [131] [124]. Notably, these psychological studies emphasize "the existence of bias that preferentially directs attention to the face at the expense of other non-facial stimuli" [132]. It can be argued that the face is the most biologically and socially important visual stimulus in the human environment. Accordingly, humans have a special ability to attract attention and provide meaningful information. Previous studies have argued that this adaptation process creates facial attention bias [133]. Due to their social and biological importance, faces are enhanced in competition for attention [134] [135].

Psychological studies claim that the face usually attracts more attention than other visual stimuli [136] [137] [138]. Humans tend to perceive faces from various objects. Furthermore,

face recognition occurs even if there is no actual face [139]. This phenomenon is known as pareidolia [140] [141] [13]. This susceptibility to face-like patterns not only is socially significant for recognizing natural faces but also tends to unconsciously seek familiar images with new perceptual inputs [142] [143] [13]. All the faces have a basic T-shaped configuration consisting of two eyes, nose, and mouth. This pattern represents a template for quickly distinguishing faces from other visual stimuli in the surrounding environment [144]. Humans tend to look at the faces of objects characterized by a T-shaped configuration. Therefore, sequences that are standardized as emoticons are immediately recognized as faces [140].

The pareidolia phenomenon affects not only simple visual illusion but also our behavior. It is reported that gaze-cue that effect joint attention, which is important in communication, is also caused by this phenomenon. Visual detection is facilitated by the pareidolia phenomenon. However, these effects do not occur unless the face is recognized [24] [25] [23]. We hypothesized that a face-like object also elicits an orienting response and attracts more attention than other visual stimuli. However, the effect does not occur unless a face-like object is recognized as a face. The present study investigated whether seeing objects as a face would influence preference.

## 5.2 Materials and methods

### 5.2.1 Participants

Twenty-five healthy, right-handed volunteers (age: 23–27 years, 1 female) with normal or corrected-to-normal vision participated in this study. Informed written consent was obtained from participants after procedural details had been explained. The Committee for Human Research of Toyohashi University of Technology approved experimental procedures. Four other participants were excluded because they did not fulfill the inclusion criteria.

### 5.2.2 Stimuli

The stimuli were 50 grayscale face-like images ( $200 \times 200$  pixel) that produced by pareidoloop (Figure 5.1). The pareidoloop software generates images by randomly superimposing polygons and calculates a face detection confidence score by a face detector when an image is generated. This software generates images repeatedly so that the calculated face detection confidence score exceeds the set confidence value. We set the confidence score to 35 (maximum) and used images with a score of 30 or higher for this experiment. The orientation of the generated image was defined as the original orientation (upright). During the stimulation sequence, each image

appeared on a uniform grey background and subtended  $1.909^\circ$  of visual angle. A small black fixation cross (subtending  $0.381^\circ$  of visual angle) overlaid the images throughout the sequence. Each stimulus was presented in 2 different orientations, either upright or inverted  $180^\circ$ .

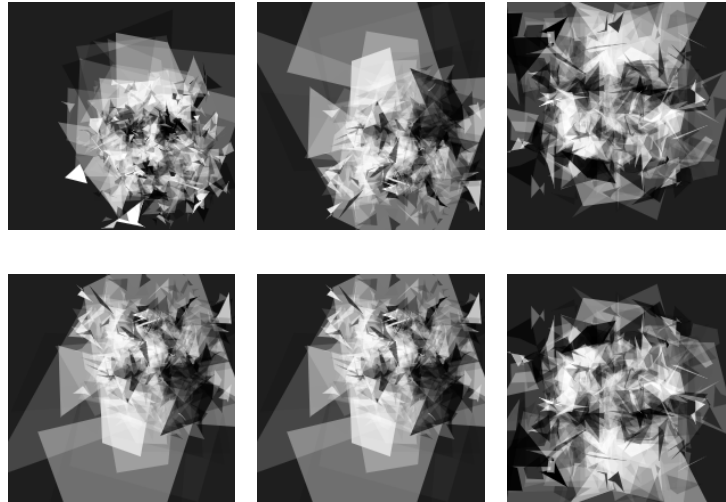


Figure 5.1: Example of stimuli.

### 5.2.3 Procedure

Participants performed the experiment under non-uniform lighting in the room. The stimulus presentation was controlled by Psychlops WebGL [145], and the stimuli were presented on a tablet (iPad gen. 7th, Apple Inc.). The viewing distance was about 50 cm. The participants performed the following two tasks. Preference task: Participants were instructed to respond in front of a monitor to select more preferred one in the two alternatives forced-choice (2AFC) task. They had to watch 50 different pairs (upright vs. inverted) of face-like images and choose one preferred image by pressing either the left or the right side (Figure 5.2).

Face-likeness evaluation task: Participants were instructed to perform face-like evaluation tasks and provided their responses by pressing 1 of 5 buttons on the tablet screen. They rated face-likeness on a 5-point scale from 1 (non-face-likeness) to 5 (most face-likeness) and were requested to respond. Participants performed a total of 100 trials (50 stimuli in each orientation), and the stimuli were presented in a pseudo-random order (Figure 5.3). We divided the participants into two groups in the order in which the tasks were performed. The group that first performed “Face-likeness evaluation task” and then performed “Preference task” was defined as “Face biased group”. The other group that first performed “Preference task” and then “Face-likeness evaluation task” was defined as “No face biased group”.

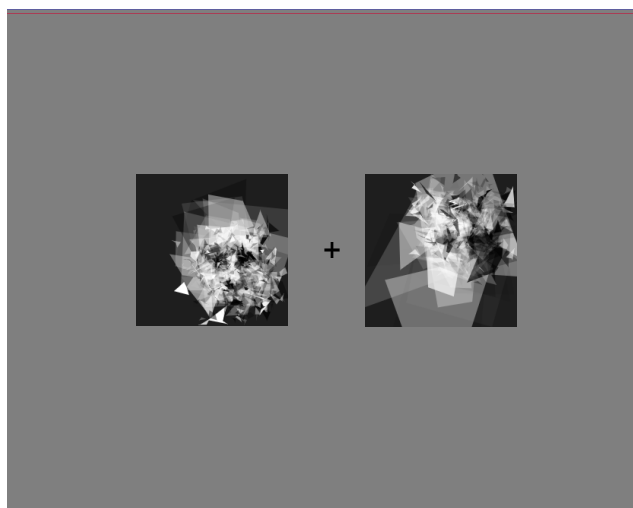


Figure 5.2: The procedure of the preference task.

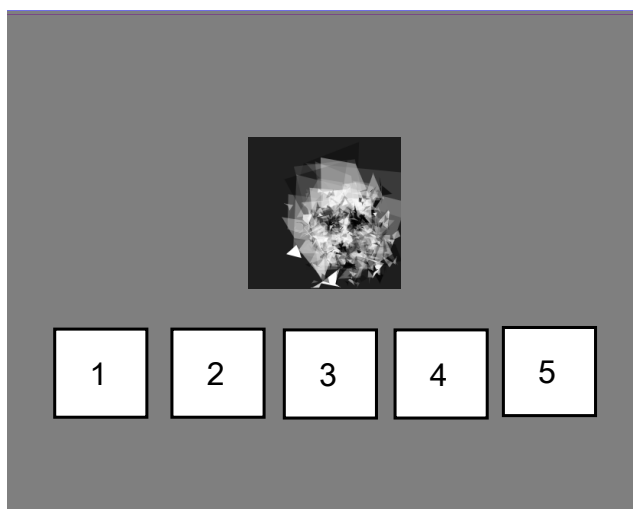


Figure 5.3: The procedure of the face-likeness evaluation task.

## 5.2.4 Analysis

### Face-likeness evaluation analysis

Face-likeness scores were computed for each group and condition and were subjected to repeated ANOVAs with Face bias or No face bias as between-subject factors and orientation (Upright vs. Inverted) as within-subject factors.

### Preference analysis

The preference selectivity rate was evaluated by means of a 1-sample  $t$ -test to determine whether the effect was significantly different from 0.5. Furthermore, the preference selectivity rate was computed for each group and condition and was subjected to repeated ANOVAs with Face bias or No face bias as between-subject factors and orientation (Upright vs. Inverted) as within-subject factors.

### Correlation analysis

Pearson's correlation analysis was performed between the preference selectivity rate and the face-likeness evaluation score for each orientation in each group. For the preference selectivity rate, we calculated the average selectivity rate of each stimulus, and for the face-likeness evaluation score, we calculated the average value of each stimulus.

## 5.3 Results

### 5.3.1 Face-likeness score

We first inspected the face-likeness score for the face-like stimuli across our two groups. (Figure 5.4 ). There were no main effects and significant interactions.

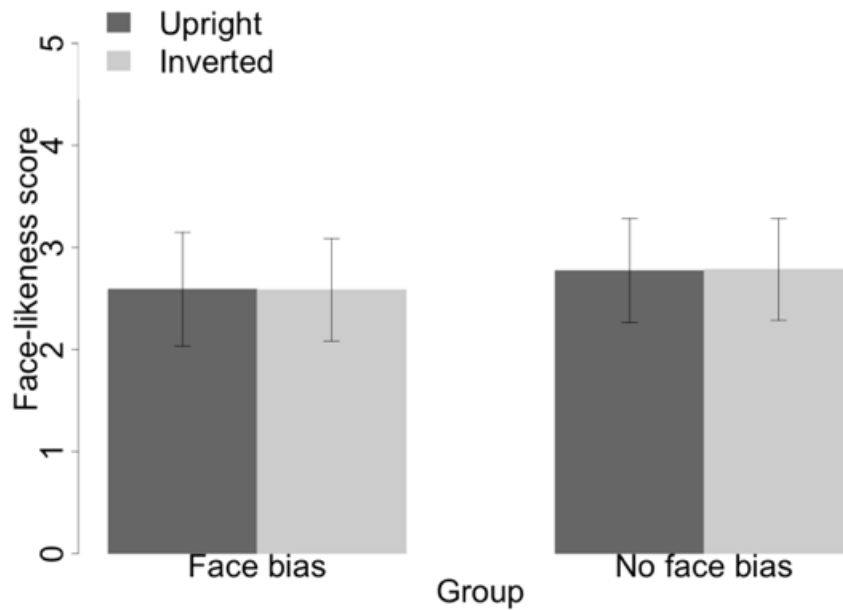


Figure 5.4: Results of the face-likeness evaluation.

### 5.3.2 Preference selectivity rate

The preference selectivity rate was then compared with a 1-sample t-test against 0.5, showing a significant selectivity rate for the face bias group in both orientations ( $p < 0.05$ ). Furthermore, we calculated the preference selectivity for the face-like stimuli across our two groups. (Figure 5.5). There were main effects of Condition [ $F(1, 11) = 8.728, p = 0.013, \eta^2 = 0.272$ ]. Moreover, the following interactions were found: Group  $\times$  Condition ( $F(1, 11) = 12.334, p = 0.005, \eta^2 = 0.385$ ). In the interaction between groups, the upright and inverted selectivity in the face-biased and the no face-biased groups showed a significant difference between groups (Upright:  $p < 0.01, \eta^2 = 0.52$  and Inverted:  $p < 0.01, \eta^2 = 0.52$ ). Furthermore, in the face-biased group, the selectivity was higher in the upright condition than in the inverted condition ( $p < 0.001, \eta^2 = 0.78$ ).

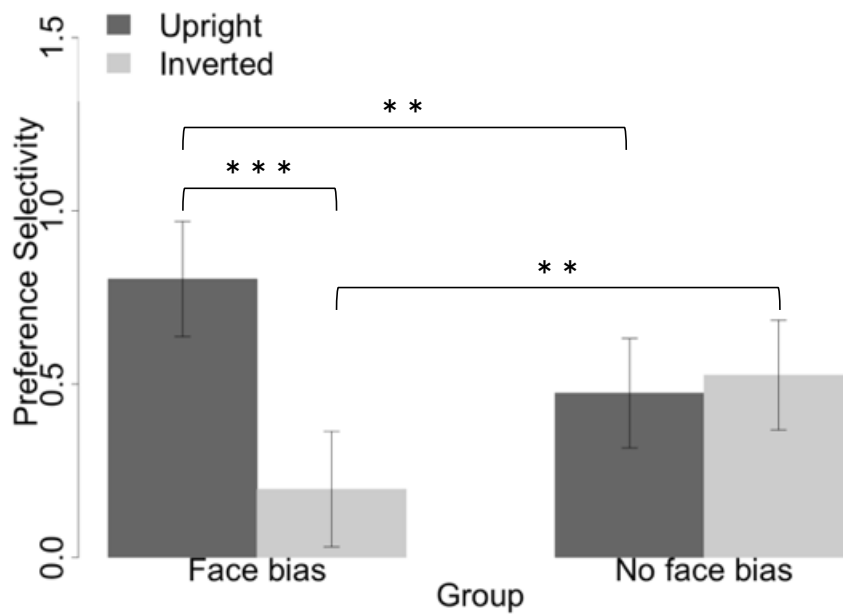


Figure 5.5: Results of the preference selectivity.

### 5.3.3 Correlation between the preference and the face-like score

We calculated the correlation between the preference selectivity rate and the face-likeness evaluation score for each orientation in each group (Figure 5.6 - 5.7 ). In the upright orientation, a significant correlation was observed between the preference selectivity and the face-like score in the face-biased group ( $r = 0.42, p < 0.001$ ), but not in the no face-biased group ( $r = 0.19, p = 0.19$  ). Furthermore, in the inverted orientation, a significant correlation was observed between the preference selectivity and the face-like score in the face-biased group ( $r = -0.37, p < 0.001$  ), but not in the no face-biased group ( $r = -0.058, p = 0.69$  ).

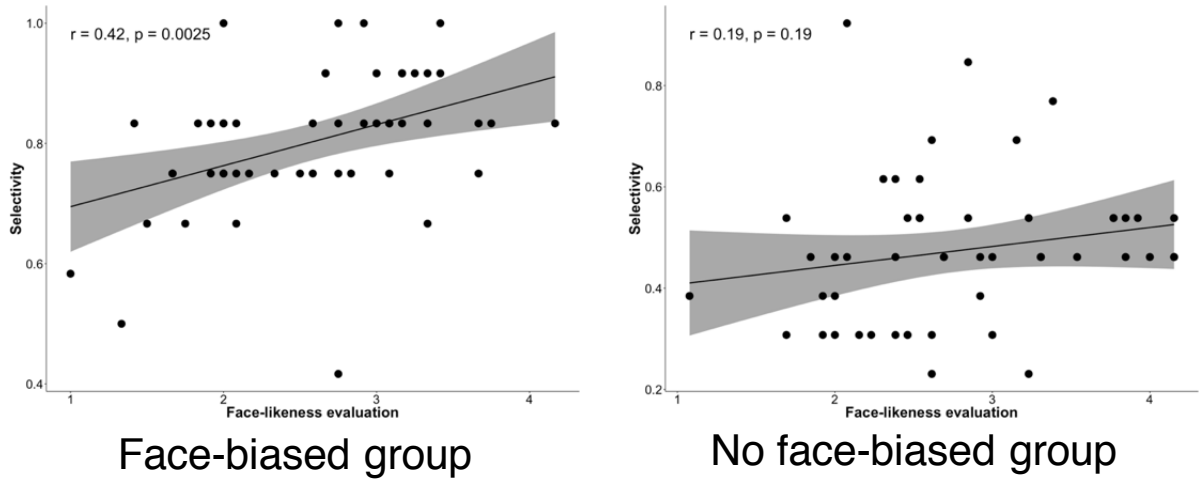


Figure 5.6: Correlation between the preference and the face-likeness evaluation score in the upright orientation. Correlation maps in the face-biased group (Left) and in the no face-biased group (Right).

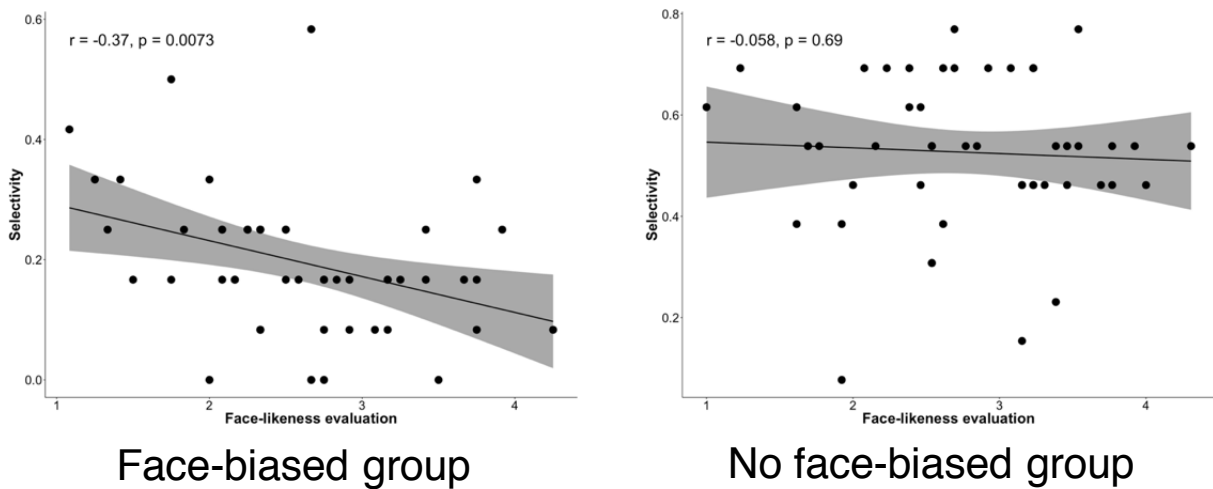


Figure 5.7: Correlation between the preference and the face-likeness evaluation score in the inverted orientation. Correlation maps in the face-biased group (Left) and in the no face-biased group (Right).



## 5.4 Discussion

The present study investigated whether seeing objects as faces affects preference using presented stimuli that could be perceived as a face or abstract painting. This study compared the following two groups: One group was biased so that the presented stimulus was perceived as a face, and another group was not. The face-biased group first performed a face-likeness evaluation task and was then presented a pair of the upright and inverted face-like stimuli. The no face-biased group first performed the preference task and then performed the face-likeness evaluation task. The results showed that the preference in the face-biased group was higher for upright stimuli than for inverted stimuli. On the other hand, there was no difference in the preference between upright and inverted stimuli in the no face-biased group. In both groups, the face-likeness evaluation score was not significantly different regardless of orientation. These results suggest that face awareness induces and strengthens preference. The task of perceiving the stimulus as a face (face-likeness evaluation task) was sufficient to improve preference. The preference enhancement for the upright stimuli was only made if participants perceived face. Previous studies have shown that facial recognition improves when participants are instructed to look at ambiguous patterns as a face [23]. In the present study, the results showed that face recognition was improved, and the preference for the face-like stimuli improved by seeing an ambiguous pattern as a face, as demonstrated in the previous study.

These results are consistent with those in previous EEG studies, which showed the top-down modulation on N170 [146] and correlation with face awareness [147] [148] [149]. For example, ambiguous patterns elicited greater N170 activity after perceiving as a face or when ambiguous patterns were reported as a face. Based on the results of these studies, seeing something like a face elicits a face-specific process, and this top-down modulation may thus enhance the detection of face-like patterns.

Moreover, it has been reported that visual attention is captured by faces [150] [151]. On the other hand, it has been shown that a face-like object has no effect on capturing visual attention [152]. However, since this study demonstrated the visual attention of face-like objects using other tasks, it is possible that visual attention might be captured by face-like objects perceived as a face in the task with a stimulus by 2AFC.

The gaze behavior, which is involved in decision making in preference judgment [153], is well known as “the gaze cascade.” The decision-making process in the gaze cascade is modeled and consists of two systems, a “cognitive assessment system” and an “orienting behavior.” The cognitive assessment system compares the template and target stimulus about the attractiveness learned by experience and outputs a signal. The orienting behavior outputs a signal from the

movement of the gaze to the target. Furthermore, these signals are sent to the decision-making module; the decision is made when the integrated signal exceeds the threshold, and the feedback is made to each system when the integrated signal does not exceed the threshold. The orienting behavior is induced by the feedback, the number of contacts with the stimulus increases, and the preference for the stimulus improves. This process is considered a “Mere exposure effect.” In addition, preferential fixation works for favorable stimuli; therefore, the number of contacts with the stimuli increases. Thus, it is assumed that the stimulus preference is improved, and the synergistic action of the mere exposure effect and preferential fixation makes the conscious preference judgment.

The present study suggests that the cognitive assessment system evaluates the facial pattern, and the orienting behavior exerts the mere exposure effect by seeing an object as a face; moreover, preferential fixation works by visual attention to face-like patterns, and the preference is further improved.

# Chapter 6

## Conclusions

### 6.1 Face-likeness perception dynamics

We clarified the dynamics of the pareidolia phenomenon using face-sensitive ERP (Chapter 2).

#### Purpose

1. To investigate at what stage of face processing the judgment of the face-likeness occurs.
2. To examine whether the inversion effect index of the N170 component actually reflects face-likeness by observing the correlation between the ERP components and behavioral reports of face-likeness.

#### Contribution

1. We confirmed that the face-likeness judgment is accomplished early in the visual cortex of the brain.
2. The inversion effect index of the face-sensitive ERP reflects face-likeness.

In this study, we examined the correlation between the face-likeness evaluation on the stimulus and the inversion effect index of each ERP component, and significant correlations were observed in the P1 component and the N170 component. These results suggest that the face-like processing or face-ness detection is performed in the early visual cortex, and these processes affect face-likeness judgment. Accordingly, face processing and face-like processing

consist of the following steps. Rough face processing, including detecting the existing shapes as eye-like, nose-like, or mouth-like, is performed in the earlier visual stages represented by P1, while detailed face processing is performed in the face detection stages represented by N170. The process of P1 to N170 components in this study may thus reflect face-likeness judgment. Furthermore, these results suggest that the face inversion index can be used as an indicator of face-likeness in early face processing.

## 6.2 Bottom-up and Top-down process in face pareidolia

We investigated how both aspects of bottom-up processing and top-down modulation contribute to face-likeness perception using EEG and pupillometry. (Chapter 3, 4, and 5). We examined the attentional modulation of rapid and automatic face-likeness detection captured by FPVS-EEG (Chapter 3). Moreover, we determined the contribution of bottom-up and top-down to the face pareidolia phenomenon using the pupillary response (Chapter 4). In addition, we tested whether seeing objects as a face would influence behavior (Chapter 5).

### Purpose

1. To Investigate how both aspects of bottom-up processing and top-down modulation contribute to face-likeness perception.
2. To clarify how biological signals change due to the pareidolia phenomenon.
3. To determine whether the pareidolia phenomenon does affect to behavior.

### Contribution

1. The pareidolia phenomenon does not occur at least in the bottom-up process.
2. The pareidolia phenomenon is not enhanced in the task involving the human face.
3. The pupil diameter is dilated by attending to face-likeness.
4. A preference for face-like stimuli emerges only if the stimuli are recognized as face-likeness.

We showed that the visual system discriminated faces automatically and rapidly in the absence of explicit attention to faces, but not face-like objects. The visual system may have a

cognitive mechanism discriminating real faces from face-like objects. In addition, in the pupil response, the enhancing effect was produced in the face-like condition, and the suppression effect was induced to make it difficult to produce face perception in the symmetry evaluation. Our findings suggest that the pareidolia phenomenon affects the pupil diameter response; the cognitive assessment system evaluates the facial pattern, and the orienting behavior exerts the mere exposure effect by seeing an object as a face. Moreover, preferential fixation works by visual attention to face-like patterns, and the preference is further improved.

### **6.3 Future works**

This study aimed to elucidate the cognitive mechanism of the pareidolia phenomenon in the human brain. In recent years, new communication methods other than face-to-face communication, such as the Internet and SNS, have become common; thus, it is possible that communication using avatars and simple patterns as a face will become more frequent. Therefore, further studies are needed to investigate the cognitive ability and processing of new social stimuli that are treated like faces, but not human faces, to improve future social life. Furthermore, to clarify these cognitive processing mechanisms, future studies are needed to improve the avatar manufacturing technology and communication with robots.

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