

Temporal dynamism of visual self-relevance recognition  
(視覚的自己関連性認知の時間的解明)

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# Declaration

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I hereby declare that the research in this thesis is the author's own original work, and the thesis has not been submitted either in the same or different form, to this or any other University for a degree.

Makoto Miyakoshi

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# Abstract

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In this thesis, temporal characteristics of visual self-relevance recognition are investigated with electroencephalogram (EEG). Visual self-relevance recognition is typically observed for animals with a large brain and complex social systems such as chimpanzees, orangutans, dolphins, and elephants. However, visual self-relevance recognition with still images is hard for them, and only humans can perform it. In the field of human experimental psychology, it is well-known that detecting targets with visual self-relevance enhances behavioral performances in hit rates and reaction times, which suggests that visual self-relevance is preferentially processed among other visual information. In order to investigate the nature of this process, a psychological model for visual object recognition was reviewed to find that Bruce and Young model (1986) is widely accepted. The purpose of this thesis is to clarify where the process of visual self-relevance recognition is located within this model.

EEG studies on Bruce and Young model have revealed the temporal dynamism of visual object recognition. The initial event-related potential (ERP) component sensitive to a visual stimulus is P100, which has the latency of around 100ms poststimulus and is recorded from occipital areas. P100 reflects visual properties of size, luminance, spatial frequency and so on. The second ERP component is N170 which has the latency of 170ms poststimulus and is recorded from occipitotemporal areas. N170 is sensitive to categorical judgment about structural features of a stimulus, such as whether face or not, or whether canonical or inverted. In a anterior part of the ventral visual pathway, N250 is elicited. N250 has the latency of 250ms poststimulus. Importantly, several studies reported that N250 is sensitive to one's own faces compared to non-self-relevant familiar faces. The last ERP component is P300 that has the latency of 300ms poststimulus and topography in parietal areas. P300 is sensitive to higher-order processes such as semantics, task-relevance, and self-relevance. From this review, the time-course of the Bruce and Young model can be roughly estimated, namely photic perception is reflected by P100, the structural encoding process by N170, representation matching by N250, and higher-order semantics by P300. It is also clear that N250 is probably related to critical processes of visual self-relevance recognition. The approach of this thesis is thus determined to clarify the nature of N250 and underlying cognitive and physiological functions involved in visual self-relevance recognition.

Previous studies have clarified only the basic nature of N250 that is the sensitivity to visual self-relevance. Moreover, those findings were limited to the facial recognition. In order to clarify other critical natures of N250, three issues should be further examined. The first one

is the domain-generalness of N250 to clarify whether representation of visual-self is processed in the abstract, domain-general manner (i.e. one's own faces, objects, names, and so on, are processed commonly in a certain cognitive module integratively). The second issue is the types of the represented familiarity with visual self-relevance; whether it is mere perceptual fluency or beyond-perceptual abstract. The third and final problem is the mechanism of the initial detection of visual self-relevance recognition. In order to approach these three issues, three empirical experiments were performed for each.

In the first experiment, domain-dependency of visual self-relevance recognition was examined. Visual stimuli were photographed objects of participant's own, familiar, and unfamiliar others'. The factorial design was 3 (Self-relevant, Familiar, Unfamiliar). Eighteen young healthy volunteers participated in the experiment. The participants' task was to watch the presented objects carefully. During the task, EEG was recorded from 16 scalp channels. Results showed that N250 discriminated only object familiarity and not visual self-relevance. The result suggested that even in the same modality (i.e. vision), self-relevance differs depending on stimulus domain, and the visual self-relevance with faces and objects are processed in different cortical areas and latencies.

In the second experiment, the issue of represented familiarity with visual self-relevance was examined. The visual self-relevance can be interpreted as 1) a result of high encounter frequency in daily life and therefore remains to be mere perceptual fluency, 2) beyond-perceptual, abstract and semantic representation specific to self-relevance. In order to determine this issue, visual familiarity was operationally dissociated into a perceptual aspect and a semantic aspect. For this design, 90 degree profile of one's own face, which cannot be seen with a single mirror, was adopted as a stimulus with low perceptual fluency but with high semantic familiarity. The factorial design was thus 2 (Frontal view, Profiled view) x 3 (Self-relevant, Familiar, Unfamiliar). Sixteen young healthy volunteers participated in the experiment. The participants' task was to judge stimulus familiarity by pressing a button. During the task, EEG was recorded from 16 scalp channels. Results showed that N250 was sensitive to both Frontal and Profiled views of one's own face. The result supported the explanation that the cognitive module for initial detection of visual self-relevance is beyond-perceptual and representations are in an abstract level.

In the third and the last experiment, mechanism of visual self-relevance recognition was examined. It has not been recommended to directly reduce the negative deflection of N250 to neural activity because scalp-recorded EEG is heavily distorted by scalp anisotropy. It is known, however, that the problem of scalp anisotropy can be treated effectively by the use of independent component analysis that calculates a spatial filter from brain to the scalp

electrodes. In addition, EEG activity can be decomposed into amplitude and phase in a time-frequency domain, and the decomposed activities explain different neuronal activities. In the third experiment, both approaches were integratively adopted. Another additional experimental factor was the visual hemifield presentation. This was for the purpose of interfering the normal processes in visual self-relevance recognition. Previous studies have shown that self-relevance recognition is dominantly processed within the right hemisphere. According to these findings, anomalous visual self-relevance recognition was expected if a self-relevant visual stimulus is delivered selectively to the left hemisphere which is allowed by the use of visual hemifield presentation. Thus the factorial design was 2 (Face, Object) x 3 (Self-relevant, Familiar, Unfamiliar) x 3 (Left hemifield, Right hemifield, Both hemifields). Twenty-four young healthy volunteers participated in the experiment. The participants' task was to judge stimulus familiarity by pressing a button. During the task, EEG was recorded from 33 scalp channels. Results showed that the interaction between visual hemifield presentation and stimulus familiarity was insignificant, so the condition visual hemifield was collapsed and the factorial design 2 (Face, Object) x 3 (Self-relevant, Familiar, Unfamiliar) was used for the further analyses. EEG data analyses revealed decrease in inter-trial phase coherency near fusiform gyrus between 200-300ms poststimulus for one's own face. The result suggests that temporal organization of neural activity is relatively low when recognizing one's own face. Such decreased neural activity is typically observed in sparse-coding network. Thus, the mechanism of visual self-relevance recognition was interpreted to be slimmer to that of the overlearned items in the long-term memory that enables rapid and low-load processes.

From above three experiments, the nature of cognitive processes involved in visual self-relevance recognition was clarified. The earliest detection was associated with one's own face, the latency of initial detection is 200-300ms poststimulus, and fusiform gyrus is responsible for this process. In this region, visual self-relevance is represented as beyond-perceptual abstract and compared to the stored representation in the long-term memory. The nature of the neural network involved in this process is innately similar to the sparse-coding network that enables rapid and low-load processes. Based on this explanation, a possible neural pathway was further considered that connects initial visual self-relevance detection to behavioral enhancement in shortening reaction time. As a result, uncinate fasciculus was highlighted as a probable candidate for the essential pathway that connects visual processing to motor output regulation. This hypothetical pathway was integrated into a model that was proposed as the summary of this thesis.

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## Chapter 1

### *When we recognize ourselves: in search for the visual self-relevance recognition*

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#### *1.1 Preface*

The famous picture drawn by Ernst Mach is the first example that emphasized how the first-person view looks (Figure 1.1). In the picture, one sees not only objects (such as a bookshelf, a floor, or a window) but also a part of the subject (such as legs, arms, and face parts including a nose, eyebrows, and mustache). No one before him had depicted the world with his or her nose. The picture even makes the watcher imagine the depth of Mach's eye socket. This sketch is often cited to explain the initial urge of phenomenology that insists the absolute priority of the first-person view before any 'objective' observation is made.

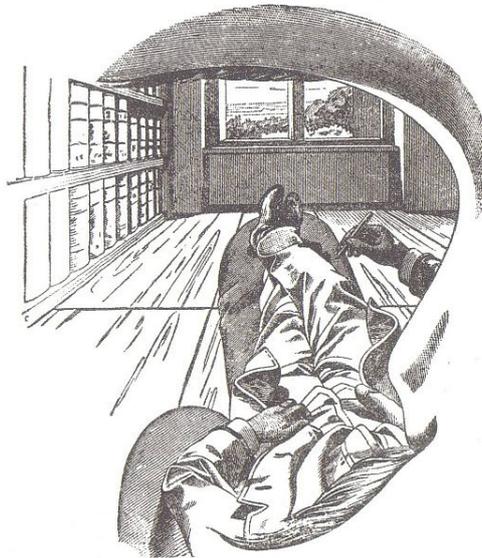


Figure 1.1 Mach's sketch.

The same motive was expressed by Wittgenstein (1922) in his early work *Tractatus Logico-Philosophicus*, but it was expressed in the other way (Figure 1.2).

5.633 Where in the world is a metaphysical subject to be found? You will say that this is exactly like the case of the eye and the visual field. But really you do not see the eye. And nothing in the visual field allows you to infer that it is seen by an eye.

5.6331 For the form of the visual field is surely not like this.

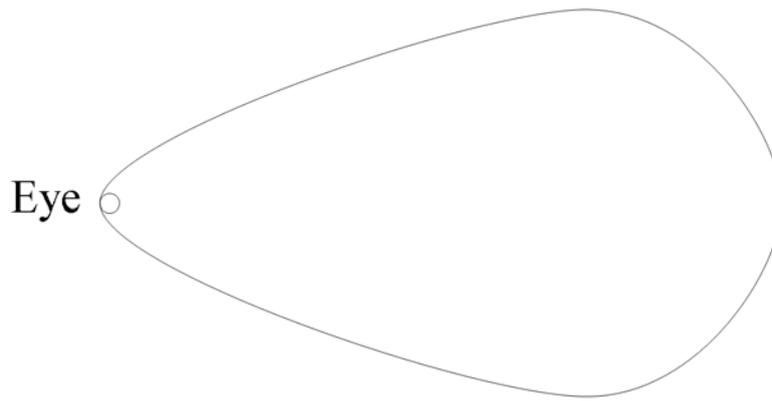


Figure 1.2 The drawing from Tractatus Logico-Philosophicus 5.6331.

He made emphasis on absence of the ‘the seeing eye’ in the visual field. Here one may notice the parallelism with Mach. Wittgenstein’s sketch show the impossible case of the visual field that is just the opposite of the Mach’s sketch. He would have drawn his own eye if he could have seen the watching eye in his visual field.

These famous philosophers together emphasized the well-known fact that you do not see yourself. In order to see yourself, you have to look into a mirror or dark water surface. One’s outlook is externalized and cannot be aware of introspectively. One must understand the nature of a mirror to figure out what one sees in the mirror. Visual self-recognition thus requires ability of meta-level cognition, which is most likely based on certain level of intelligence. Among other animals, human beings are endowed with outstandingly high intelligence. Evidence has suggested involvement of complex processes and mechanism during visual self-recognition (e.g. Sugiura et al., 2008). However, initial detection of visual self-relevance in the flow of visual input is poorly understood. The present thesis is dedicated to clarify when and how visual self-relevance is detected.

### *1.2 Visual Self-relevance Recognition*

In this section, human-specific aspect of visual self-recognition is highlighted. Empirical evidence provided by experimental psychology is reviewed to confirm that visual self-recognition is associated with robust behavioral enhancement. To understand how this process occurs, a model for the visual recognition processes proposed by Bruce and Young (1986) is referred, which plays a central role in the present thesis. Finally, the main research question of this thesis is addressed.

### *1.2.1 Inter-Species Comparison*

A mirror self-recognition paradigm is a representative experiment that examines the basic ability of visual self-recognition. It examines whether a subject recognizes his or her own mirror image as him/herself and shows self-oriented behavior by watching the mirror. This test is often performed as a marking test, which examines whether a subject attempts to reach an adhesive material attached by experimenters. This is a test of contingency understanding, which is mediated by temporal synchronization between efferent motor outputs and its afferent visual feedback from the mirror image (Happe et al., 2003). To date, only the limited number of species passed the test. These species include chimpanzees (Gallup, 1970), orangutans (Lethmate and Ducker, 1973), dolphins (Reiss and Marino, 2001), and elephants (Plotnik et al., 2006), in addition to, of course, human beings. These species are endowed with large brains and developed sensory organs, and organize highly sophisticated societies. It has been therefore widely accepted that the ability to pass this test should be related to higher-order cognitive functions.

### *1.2.2 Two-Types of Visual Self-relevance Recognition: Contingency and Semantics*

The assumption that mirror test performance reflects intelligence is nonetheless questioned by recent studies. For example, magpies, a type of songbird species, showed mirror-induced behaviors (Prior et al., 2008). Similarly, oval squids also showed possibility of mirror-induced behavior (Ikeda and Matsumoto, 2007). Evidence from these non-mammalian animals undermined the assumption of the relation between mirror test performance and higher-order cognitive functions that is often associated with mammalian species with large brains, which is apparently not the case with magpies and oval squids.

This nonetheless does not deny the significance of the ability in mirror self-recognition. Understanding of visuo-motor contingencies is not all what visual self-recognition is, since we recognize ourselves in still pictures. There are two types in mirror self-recognition, and the other type can be thus performed with static images via semantic representations. So far, no animals other than human beings have shown this ability. It should not be too much to say that this type of semantic visual self-recognition is one of abilities that are human-specific.

### *1.2.3 Visual Self-relevance Recognition in Humans: Approach by Experimental Psychology*

If the visual self-relevance in the semantic term is distinguished from other information,

critical condition for the detection is of interest. In order to elucidate it, empirical evidence is necessary to explain the nature of our visual recognition. In the literature of experimental psychology, visual self-recognition has been most frequently examined with one's own face. In the classical visual self-recognition study performed by Tong and Nakayama (1999), two important behavioral aspects were emphasized in self-face recognition. One is that one's own face is detected faster than other targeted faces of unfamiliar persons, and the other is that self face recognition is robust to viewpoint changes. Tong and Nakayama concluded that self-face recognition is associated with rapid processes, vast amount of experiences, viewpoint-independent representation, enhanced detection, and less attentional resource requirement. This strongly suggests prioritized cognitive processes dedicated for self-face recognition. From the viewpoint of evolutionary psychology, Sedikides and Skowronski (2003) insisted that considerable selective pressures must have existed in the history of mankind to direct attention to self-relevant information, most likely after establishment of human society. Potentially high survival value may have been associated with self-relevant information because rapid detection and response are parts of elementary functions for socially adaptive mechanism such as threatening face detection (Öhman et al., 2001). These authors together emphasized significance of behavioral enhancement in visual self-recognition.

#### *1.2.4 Necessity for Visual Process Model*

It is noteworthy that prioritized cognitive processes are recruited when visual self-recognition is performed. The question is how it is performed. To answer this question, it is a good approach to use an established model of the ordinary visual recognition processes first, and then underpin which specific process is responsible for visual self-recognition. This approach is reasonable in the point that the model of visual recognition processes would provide evidence-based constraints upon the concept of visual recognition, which serves as segmentation of visual recognition processes and clarifying the contents of each segmented process. With this approach we can pick up visual processes that seem critical to visual self-recognition.

#### *1.2.5 Selection of Visual Process Model*

It would not be too much to admit that the most widely accepted model of visual recognition is the one proposed by Bruce and Young (1986). When this model was published it was too early for neuroimaging studies, so the explanation for the relation between cognitive

processes and the underlying neuronal mechanism was constructed mainly by neuropsychological evidence. This model is often referred to as classic, but the fact that many of ERP as well as fMRI studies have been referring to this model indicates the quality of this model (e.g. Eimer, 1998; Eimer, 2000; Herzmann and Sommer, 2007; Itier and Taylor, 2004; Pfützte et al., 2002; Pickering and Schweinberger, 2003; Schweinberger et al., 1995; Schweinberger et al., 2002a; Schweinberger et al., 2002b; Schweinberger et al., 2004). This model has been accepted so widely that it is now hard to find a empirical study that is based on other model when performing a study on visual recognition, except for the cases of modified versions of the Bruce and Young model (e.g. Burton et al., 1990; Valentin et al., 1995; O’Tool et al., 2002).

Their model includes three domains of visual recognition, namely objects, faces, and letters (see Figure 1.3), and each domain consists of four stages before naming response. In healthy normal young volunteers, the average reaction time to detect the visual stimuli is typically around 500 ms in easy tasks, which gives the Bruce and Young model a basic time-scale; all of the processes depicted in the model should be carried out within 500ms. The question of the present research is when the self-relevance is visually detected in this 500ms. To answer this question, it is necessary to obtain empirical data to clarify the time-course of visual self-recognition. Considering possible candidates for the initial self-relevance detection, the Bruce and Young model suggests the following four modules: Photic perception, Structural Code, Recognition Unit, and Person Identity Node. Now the question is which one is responsible for the first detection of visual self-relevance.

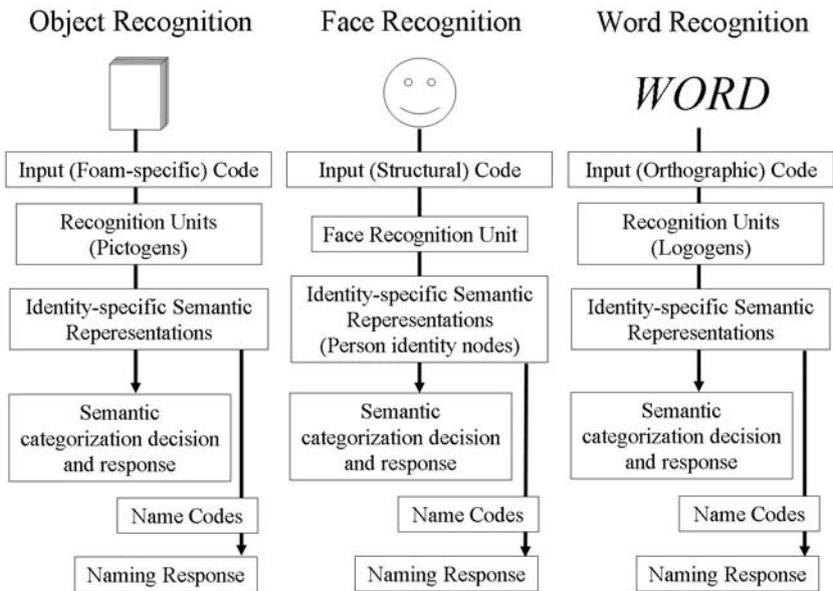


Figure 1.3 The visual recognition model adopted from Bruce and Young (1986).

### *1.3 When Self-relevance is detected: investigating the temporal profile with EEG*

To underpin the first module that detects self-relevance, clarifying temporal dynamics of visual self-recognition is necessary. The issue of temporal dynamics is also represented in the Bruce and Young model, but it remains only qualitative and lacks hard evidence that helps to determine the critical latency in millisecond. Fortunately, the Bruce and Young model was later intensively studied by researchers of the event-related brain potential (ERP) study, which is a mainstream of electroencephalogram (EEG) studies today. Unlike activation studies using positron-emission tomography (PET) or functional magnetic resonance imaging (fMRI), EEG has a high temporal resolution and is suitable to examine temporal dynamics. ERP measures peri- and after-stimulus EEG that is later averaged across trials that belong to the same conditions. It is one of major non-invasive measurements of electrical activity elicited by the central nervous system. From the technical viewpoint of EEG recording, investigating visual processing stages with ERP is suitable from anatomical reason. Visual pathway runs the surface of cortex and can be organized into two anatomical pathways: the ventral pathway directed toward the inferotemporal cortex (IT) and the dorsal pathway directed toward the inferior parietal lobule (Figure 1.4; Mishkin and Ungerleider, 1982). This structure allows us to observe relatively clear ERP modulations. Thus, ERP researchers performed experiments in search of ERP correlates of the modules in the Bruce and Young model and successfully identified ERP correlate for the processing modules.

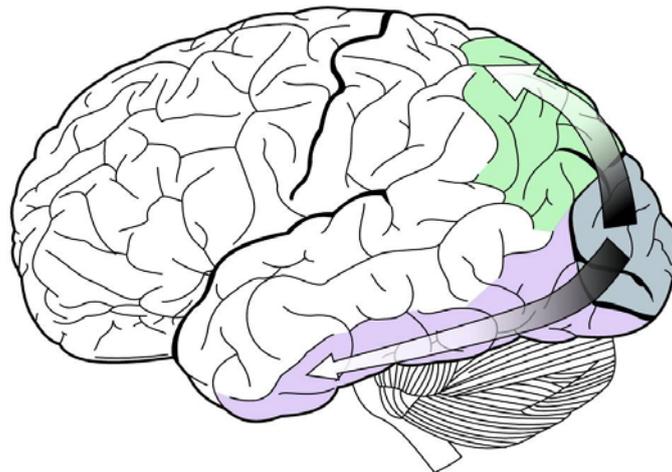


Figure 1.4 Two visual pathways originated from V1 (gray), dorsal (green) and ventral (purple) streams. Cited from Wikipedia under the terms of the GNU Free Documentation License.

#### *1.3.1 The Time-Course of the Bruce and Young model provided by ERP studies*

In below, previous findings in ERP studies on visual recognition are reviewed to confirm the basic temporal profile of the processes involved in visual recognition. One of the visual recognition processing stages, especially Recognition Unit and its ERP correlate N250, is focused as the index of particular interest.

#### *1.3.1.1 Photic perception and P100*

The initial visually evoked potential is P100. This component has its electrical source near V1. It has the earliest latency (around 100 ms after stimulus onset) among all visually evoked potentials. It shows parametric modulation to psychophysical manipulation on visual stimuli (e.g., Allison et al., 1999). It suggests that highly sensational aspects of stimuli are processed at this stage. This explanation leads to the consideration that P100 is unlikely to reflect semantic feature of the stimuli such as self-relevance. In line with this theoretical inference, hardly any evidence is found in the ERP literature that reported semantic sensitivity of P100. This earliest stage can be thus safely excluded from the target of the present study since the research interest is the initial detection of visual self-relevance.

#### *1.3.1.2 Structural Encoding and N170*

After V1, the neural pathway of visual perception is split into two routes: the dorsal stream and the ventral stream, as we have seen in Figure 1.4. The dorsal stream is known as the ‘where pathway’ or ‘how pathway’, which is associated with perception of motion, representation of object locations, and control of the own body parts, eyes, arms, to guide saccades, or reaching, all of which require coordination with visual information (Goodale and Milner, 1992). On the other hand, the ventral stream, also known as the ‘what pathway’, is associated with form recognition and object representation. The advanced stages of the ventral pathway are associated with storage of long-term memory about person and object information. Visual self-recognition in the semantic term is most likely related to the functions in the ventral stream. This view is also supported by anatomical observation. Investigation of pyramidal cell morphology in ventral stream areas showed a consistent trend for neurons to become larger, more branched, and more spiny in progressively “higher” (i.e. anterior) stations, which contrasts with comparatively mild and less predictable variations among dorsal stream areas (Elston and Rosa 1997, 1998).

N170 is the ERP component of the early stage of the ventral stream whose peak latency is around 170ms after stimulus onset. The anatomical source of N170 is the fusiform gyrus

(e.g. Deffke et al., 2007). It is well established that fusiform gyrus plays a central role in face recognition (Grill-Spector et al., 2004). Haxby et al. (2000) called it as the core system of the face recognition. In correspondence with these studies, the face-specific sensitivity of N170 was reported by Bentin et al. (1996). They also showed that N170 distinguishes upright faces from inverted faces. It suggests that N170 is sensitive to canonical view of faces, which requires, importantly, a certain level of content analysis. However, it was also demonstrated that N170 does not distinguish person identities or familiarities (Eimer, 2000; Puce et al., 1999; Schweinberger et al., 2002a). The sensitivity of N170 is thus considered to be limited to detecting structural properties of faces, which is in harmony with the explanation by Bruce and Young (1986) for the Structural Coding Unit. The widely accepted view is that N170 is linked to late stages of structural encoding where representations of global (but anonymous) face configurations are generated in order to be utilized by subsequent face recognition processes (Eimer, 2000). In other words, N170 is the index of perceptual features rather than semantic representation. However, although the number is limited, there are several studies that reported N170's sensitivity to stimulus familiarity (e.g., Caharel et al., 2002, 2005; Jemel et al., 2003). The reason of this inconsistency is not clear yet. From what reviewed above, it is not very likely that Structural Coding Unit is involved in visual self-recognition. However, for the validation purpose, it is a reasonable approach to confirm the sensitivity of N170 to visual self-representation.

### *1.3.1.3 Recognition Unit and N250*

After the structural encoding process, input visual information is processed by Recognition Unit. According to Bruce and Young (1986), this unit is responsible for person identification by referring to the 'stored representation' in the long-term memory and matching input information to the retrieved information (e.g. Pfütze et al., 2002). This function is of particular importance to the present research, since visual self-relevance recognition is definitely a part of the processes involved in person identification.

The ERP correlate of Recognition Unit was found initially as N250r and later as N250. Their latency is around 250ms poststimulus. The difference between the two is the suffix 'r', which comes from 'repetition' that was the key element to elicit N250r. N250r is elicited for the target stimuli in immediate priming paradigm in which the identical pair of visual stimuli, the prime and the target, are presented successively (or sometimes intervened with a couple of trials). The early ERP studies on the immediate priming effect already revealed that N250r is sensitive to semantic familiarity (Begleiter et al., 1995; Schweinberger et al., 1995). They

named this phenomenon as early repetition effect (ERE), which is the other nomenclature of N250r. There are two important natures in N250r. The first one is viewpoint-robustness in familiar but not in unfamiliar faces (Schweinberger et al., 2002a). This was demonstrated in the following experiment. Same person's different views are presented as prime and target to ask if perceptually different but semantically same personal identity causes the priming effect (=N250r modulation). Results showed N250r modulation, but only for familiar faces. The authors interpreted the results as successful matching of the stored familiar face representation and the presented face. The other important nature of N250r is the effect of personal relevance as a modulator (Herzmann et al., 2004). It suggests that Recognition Unit represents personal relevance differently from non-personal familiarity. Unfortunately, there is no N250r study dedicated for visual self-recognition. This is due to the limitation that in immediate priming paradigms a stimulus is presented only for twice, so it requires many variations of stimuli to keep relatively large number of trials for ERP analysis (usually minimum 20), which is hard to prepare in the case of one's own face.

In contrast to N250r studies, some of N250 studies focused directly on visual self-recognition (though they are all limited to self-face recognition). It was first reported by Caharel et al. (2002). They presented one's own face repeatedly and found the N250r-like component that reflected self-relevance. They did not refer to the resemblance of the component to N250r and called it N2. The significance of this study is that it is the first report of self-sensitive ERP component other than P300. Later, Tanaka et al. (2006) replicated the finding, and formally called it N250 without the suffix 'r' for the first time.

The review on ERP component indicates that surprisingly little evidence is known about the role of Recognition Unit in visual self-recognition, although Recognition Unit is the most promising candidate for the first detector of visual self-relevance. Currently, only two studies are available for the research of relation between self-relevance and Recognition Unit. In order to clarify the initial detector of visual self-relevance, the functional role of Recognition Unit should be investigated to the further extent. This issue is of special importance to the present research, and will be revisited in the other section.

#### *1.3.1.4 Person Identification and P300*

The most replicated EEG evidence of self-recognition is P300. The latency of P300 is approximately 300-500ms poststimulus. This latency is almost overlapping the reaction time, which suggests that P300 reflects the late and advanced stage of cognitive processing (it should be noted that the latency and amplitude of P300 depend on the nature of task. e.g.

Johnson, 1986). It reflects various processes involved in self-relevance recognition, regardless of domain and modality (vocalized one's own name, Berlad & Pratt, 1995; Folmer & Yingling, 1997; Perrin et al., 1999, 2005; see also Müller & Kutas, 1996; visually presented one's own name, Fischler et al., 1987; autobiographical information, Gray et al., 2004; one's own face, Ninomiya et al., 1998; Tanaka et al., 2006). The reason for this broad sensitivity is that P300 has been traditionally considered to be the index of higher-order cognitive function, such as attentional modulation and reallocation of cognitive resources (e.g. Johnson, 1986; Kok, 2001). Self-relevance is only one of sufficient conditions of P300. Interpretation of P300 modulation in a self-relevant task thus should be made carefully. For example, Gray et al. (2004), mentioned that P300 augmentation in their self-relevant recognition task is due to attentional modulation that is reliably caused by self-relevance.

P300 reflects activation of the late stages of information processes which is highly integrated, so stimulus domain or modality does not matter any more. This is in harmony with the assumed nature of Person Identity Node in the Bruce and Young model. It strongly suggests that Person Identity Node is likely to be too distant from the initial detection of visual self-relevance.

### *1.3.2 Potential Target in the Present Research: Recognition Unit*

The research interest in the present study is to underpin the detection of self-relevance in visual self-recognition. From what reviewed above, Recognition Unit is the most promising candidate compared to others. The nature of N250 is intermediate in several important ways compared to N170 and P300. The latency of N250 is between N170 and P300. N170 is sensitive to Structural Encoding and rather perceptual and insensitive to person familiarity, whereas P300 reflects the higher-order abstract cognitions and non-specific to vision. The estimated electrical source of N250r, provided by Schweinberger et al. (2002), was anterior to the source of N170, suggesting that N250r reflects more advanced process than N170. These findings may indicate that Recognition Unit is located in the middle of bottom-up sensory information input and top-down information processing.

Little is known, however, about the role of Recognition Unit in visual self-recognition, as we have confirmed above. Two central questions should be answered, namely *when question* and *how question*. The *when question* concerns clarifying temporal dynamics in detection of self-relevance and identifying which module in the Bruce and Young model is responsible for it. The *how question*, on the other hand, aims to explain the nature of Recognition Unit. From what is reviewed above, it seems reasonable to start with the

assumption that Recognition Unit is the first stage in detecting visual self-relevance.

#### *1.4 Purpose of the present study*

The research interest in this thesis is to underpin the detection of visual self-relevance. The ERP studies on the Bruce and Young model suggest that Recognition Unit is the promising candidate, but the detail remains unclear. Empirical evidence is necessary to further clarify the nature of Recognition Unit. Thus, the purpose of the present study is to answer the following two questions:

1. *When question*: to clarify the time-course of detecting self-relevance in visual recognition, and underpin the responsible module in the Bruce and Young model.
2. *How question*: to provide the possible mechanism that explains the nature of the detection process.

In the following sections, the previous findings in literature are summarized, and their problems are analyzed in detail. Then, the goal of this study is addressed

##### *1.4.1 Summary of the previous findings*

Based on neuropsychological literature, Bruce and Young (1986) proposed the model that explains visual recognition. One of the characteristic features of their model is the flow of visual processes from upstreams to downstreams i.e. from perception to cognition. The arrangement of these modules in the ventral stream has been investigated by ERP researchers, owing to superior temporal resolution of EEG. They found ERP components that correspond with the modules in the Bruce and Young model and thus provided the temporal profile to the model.

The Bruce and Young model contains Photic perception stage, Structural Encoding Unit, Recognition Unit, and Person Identity Node, which correspond to P100, N170, N250, and P300, respectively. Among these, Recognition Unit is of particular interest from its functional significance as well as latency in its time-course. ERP evidence was provided by Tanaka et al. (2006) that showed that N250 is sensitive to visual self-representation, which provided replication to Caharel et al. (2002) who reported most probably the same phenomenon.

### 1.4.2 Problems in previous studies

There are several critical limitations in the previous studies. The first limitation is the insufficient number of studies dedicated to this issue. There are actually only two studies available. Moreover, one of the two claimed that they found N170 modulation by self-relevance (Caharel et al., 2002), which was denied by majority of other researchers. This makes the reliability of their results questionable. The other study, conducted by Tanaka et al. (2006), succeeded in rather clear demonstration of self-sensitive N250, but their finding mainly concerns only *when question* and not much about *how question*. To answer to the *how questions*, three issues should be clarified.

The first issue concerns domain-generalness of Recognition Unit. The available ERP studies all employed the face recognition paradigm, but visual self-recognition is not necessarily limited to face recognition. It is not clear whether or not the detection of visual self-relevance is affected by object domain. The cross-domain evidence is necessary to generalize the finding in the self-face recognition.

The second issue is about the type of represented familiarity. Schweinberger et al. (2002) indicated that N250r is sensitive not only perceptually but also semantically. It indicates that the nature of Recognition Unit is beyond-perceptual. It is not clear, however, whether this is also the case of N250 in visual self-recognition. There is no study so far that explicitly asked whether N250 reflects self-specific representation that is beyond-perceptual. It is thus necessary to determine whether visual self-recognition is mediated by perceptual fluency or semantic familiarity within Recognition Unit.

The last issue is the mechanism of Recognition Unit. In the Bruce and Young model, the functional role of Recognition Unit is to match the input information to the stored representation. This speculation nonetheless lacks physiological evidence. For example, it remains unclear what type of the neural network model explains this function. Psychophysiological evidence that explains the mechanism of Recognition Unit is required. In below, each of the three issues will be addressed in detail.

#### 1.4.2.1 Domain-Generalness

Previous ERP studies on N250 commonly used one's own face as representative self-relevant visual stimuli. However, the assumption was recently questioned. Sugiura et al. (2008) reported that the cortical network recruited for seeing one's own face is not necessarily domain-general. In their experiment, one's own face and their written name were presented to

participants to confirm if there is overlapping cortical areas in two tasks. Results failed to find the crossover activation. The result suggests domain-dependent cortical networks for each domain. Face recognition in human beings is one of critical social abilities since a face contains rich social information (e.g. Haxby et al., 2000). This view is also supported by another neuroimaging evidence that there are brain areas within fusiform gyri that are exclusively dedicated for face recognition (Grill-Spector et al., 2004). These findings indicate that face recognition is rather an exceptional case, and it may be inappropriate to generalize the result of face recognition to other object recognition such as items and names.

In relation to this finding, it is worth noting that N250r showed face-selective sensitivity (Schweinberger et al., 2004). This may be related to the fact that the estimated electric source of N250 is located within fusiform gyri (Schweinberger et al., 2002a). These findings suggest that Recognition Unit could be tuned especially for face recognition. This may also be related to the fact that the Bruce and Young model has three distinct domains, namely faces, objects, and letters. If visual self-recognition is affected by stimulus domains, then evidence from face-recognition is not representative any more and should not be generalized to the cases of other domains. However, available ERP evidence is all based on self-face recognition.

In order to evaluate the effect of stimulus domain on Recognition Unit, it is necessary to compare different domains in visual self-recognition. Following the Bruce and Young model, it seems reasonable to assume domain-dependency also in visual self-recognition. The alternative hypothesis in this case is the assumption of domain-generality in visual self-recognition. Unfortunately there is no empirical evidence so far to exclude the possibility of this alternative hypothesis, so the experiment focused on this issue is necessary. The domain-generality of the Recognition Unit thus should be tested to clarify whether differences in domains affect the initial stage of visual self-recognition.

#### *1.4.2.2 Represented Familiarity*

In the Bruce and Young model, the function of Recognition Unit is to match the input information to the stored representation. However, the detailed explanation about what is matched is lacking. Troje and Kersten (1999) raised an important question regarding this issue. They assumed that there are two types of visual familiarity, namely perceptual and semantic. These operational definitions provide a reasonable starting point to argue distinction between familiarity via quantity (e.g., encounter frequency) and familiarity via quality (e.g., semantic uniqueness). They asked whether the self-relevance can be explained by perceptual fluency or semantic uniqueness. They prepared frontal and profiled view of one's own face, and defined

that frontal view is familiar in both perceptually and semantically while the profiled view of that is only semantically familiar and perceptually non-familiar (since we can not see our profiles unless using multiple mirrors or taking photos). They measured reaction time to detect self-other distinction by naming the presented stimuli, and showed much delayed RT for one's own profile. They concluded that visual self-recognition is mediated by perceptual fluency and not by semantic familiarity.

To determine what is represented in Recognition Unit, starting from distinguishing perceptual fluency from semantic familiarity is essential. Unfortunately, the study conducted by Troje and Kersten (1999) does not provide a direct reference to the visual self-recognition. The similar design can be found in the ERP study performed by Schweinberger et al. (2002). They demonstrated that N250r show the priming effect even when the target is primed with the same person's face but with different facial angle, as long as the person is familiar. However, this study does not provide a clue to the case of visual self-recognition, either. On the other hand, previous ERP studies performed by Caharel et al. (2002) and Tanaka et al. (2006) showed only frontal view of faces, so it is unable to examine whether visual self-recognition is really mediated by perceptual fluency or not.

In order to determine the type of represented familiarity by Recognition Unit, it is necessary to compare N250 responses to viewpoint-variant one's own faces. If N250 is affected by facial views, then it would support the possibility that visual self-recognition is mediated by perceptual fluency. If not, then it would support the possibility that it is via semantic familiarity.

#### *1.4.2.3 Mechanism*

The assumed function of Recognition Unit was originally conceptualized from neuropsychological evidence. It is true that neuropsychology provides valuable insights that are hard to obtain from normal volunteers. Nonetheless, evidence from these reports remains circumstantial. The assumed matching process in Recognition Unit does not contradict with empirical evidence, but the explanation suffers from lack of a mechanism model. Due to this limitation, the current explanation of how Recognition Unit functions remains speculative.

The functionality of Recognition Unit should be explained by changes of neural network states. There are two basic types in neural networks: population coding and sparse coding. Each of the models will be address below.

#### *1.4.2.3.1 Population Coding*

Population coding is characteristic for gross increase of network activation when accessed, for information is represented by activation of network nodes. An example of population coding is the spreading-activation theory (Collins and Loftus, 1975). In this model, activation occurred in a given node spreads out to the next nodes along the paths of the network with decreasing activation level, which result in increase of activation in the gross network. This explanation seems to agree with semantic processes which show associative nature.

#### *1.4.2.3.2 Sparse Coding*

In contrast, the other type of the neural network models is characterized by relative decrease in activation. This model was proposed for the explanation of repetition suppression (Desimone, 1996; Grill-Spector et al., 2006; Wiggs and Martin, 1998), a characteristic activation decrease for primed and repeated stimuli. Quite importantly, N250r is a typical index of repetition suppression (Schweinberger et al., 1995, 2002, 2004; Pickering and Schweinberger., 2002; Pfützte et al., 2002; Begleiter et al., 1995). Although these ERP studies commonly demonstrated familiarity-related negative enhancement of both N250 and N250r (Schweinberger et al., 2002a; Herzmann et al., 2004; Caharel et al., 2002, 2005; Tanaka et al., 2006), it does not assure actual decrease in neural activity due to the limitation of ERP approach. This limitation is addressed below in detail.

#### *1.4.2.3.3 Technical limitation in making inference with conventional methods*

Scalp-recorded EEG is severely distorted by scalp anisotropy i.e. heterogeneous tissue layers comprised of cerebro-spinal fluid, dura mater, bones, skin, etc, in addition to electrical diffusion due to volume conductance. It is a basic rule in ERP studies that positive or negative potential should not be directly associated with increase or decrease of neural activity, respectively. It is therefore hard to make a valid inference about neural state from ERP results. In order to clarify the mechanism underlying Recognition Unit, it is mandatory to overcome this technical limitation and exploit more information from EEG. However, this still remains a challenge in the majority of EEG studies. The case of ERP investigation on Recognition Unit is just one of problems that derive from this limitation. In other words, many consider N250 and Recognition Unit as relevant to the issue of repetition suppression, no one could provide direct evidence with EEG. This is one of the reasons why the issue of mechanism has been

carefully avoided in the study of EEG researches.

#### *1.4.3 Goal of the present study*

The goal of the present study is to provide new empirical evidence that answers both *when question* and *how question* about initial detection of visual self-relevance. For this purpose, EEG, a non-invasive method to measure activity of the central nervous system is required for its superior temporal resolution. For the framework of the research, the Bruce and Young model is borrowed as the empirical constraint. One of the contained modules, namely Recognition Unit, is intensively focused for it is a promising candidate for the initial detector of the visual self-relevance from previous findings.

#### *1.5 Preparing empirical studies for the present research questions*

To clarify the nature of the initial stage of visual self recognition, three aspects of the process should be clarified. These are domain-generality, represented familiarity, and the neural mechanism, of Recognition Unit. To provide empirical evidence to the issues, experiments are designed for each. Below, the details are addressed.

##### *1.5.1 Domain-generality of visual self representation in Recognition Unit*

The first experiment is about the domain-generality of Recognition Unit. The necessity of this study comes from the fact that previous N250 studies all employed self-face and did not examine non-facial objects, as we have already reviewed above. The important concern is that self-face may not necessarily be representative as self-relevant visual stimulus. If the initial detection process depends on stimulus domain, then temporal dynamics of detecting visual self-relevance should also be determined to be domain-dependent.

To examine this issue, it is reasonable to replicate Caharel et al. (2002) with modification in presenting objects, instead of faces, with three levels of familiarity, namely self-relevant, familiar, and unfamiliar. In attempting to test the domain-generality of visual self-relevance, Sugiura et al. (2008) chose the method of presenting one's own faces and names in search of overlapping neural module. However, written names are artificial symbols (words) and qualitative discontinuity from faces is not negligible. In order to allow straightforward comparison, it is more reasonable to present objects in contrast to faces, since they are at least in common to be concrete objects. Other experimental parameters should be

as same as possible to the previous study to allow comparison across the object domains. The primary purpose of the first experiment is to ask whether N250 to visually presented objects dissociates visual self-relevance as was confirmed in the case of faces. The Bruce and Young model suggests domain-specific N250 response, which leads to the prediction that visual self-relevance with objects is not dissociated from mere familiar objects.

### *1.5.2 Represented familiarity by Recognition Unit*

The second experiment should be designed to determine whether representation by Recognition unit is perceptual or semantic. This approach requires dissociation of semantic familiarity from perceptual fluency, which was found in Troje and Kersten (1999) or Schweinberger et al. (2002). For designing the study, it is reasonable to adopt these paradigms. The experimental design requires the condition Viewpoint (frontal and profile) and Familiarity (Self, Familiar, and Unfamiliar). The domain of visual objects should be faces, because view canonicity is the key factor in this design, which objects do not have (Biederman and Gerhardstein, 1993). The main interest of this study is to measure N250 response to one's own face with high or low perceptual fluency. Results from Schweinberger et al. (2002) provides indirect evidence that supports the possibility of view-independent facial representation in Recognition Unit, which would result in equal N250 to either frontal or profile view of one's own face.

### *1.5.3 Mechanism underlying Recognition Unit*

In the third experiment, the neural mechanism underlying Recognition Unit is examined. For this purpose, it is important to obtain empirical data to determine which of neural network models, the population model or the sparse coding model, is appropriate to explain the initial detection of visual self-relevance.

For cognitive tasks, the established stimulus set in previous experiments, namely faces and objects of one's own, familiar, and unfamiliar, are again employed. In addition, hemispheric difference in visual self-recognition is tested. Review on literature suggests that cortical networks dedicated to self-recognition are almost uniquely right-lateralized (for neuropsychology, Feinberg and Keenan, 2005; Keenan et al., 2001, 2003; Sperry et al., 1979; Van Lancker, 1991; for behavioral evidence, Keenan et al., 1999, 2000a, 2000b; Platek et al., 2004a; for reviewing fMRI evidence, Northoff et al., 2006). Historically, these findings have led to the right-hemisphere dominance hypothesis in self-recognition (for review, Keenan et

al., 2000b; Van Lancker, 1991). This hemispheric difference concerns the mechanism of initial detection of visual self-relevance and should be examined. For this purpose, visual field manipulation was introduced as another experimental condition in an attempt to interfere with normal visual recognition (Brown and Jeeves, 1993; Brown et al., 1999). From these findings, it is predicted that self-relevant stimuli presented to the right visual hemifield would lead to anomalous self-recognition. The artificially introduced anomalia in visual self-recognition was expected to help identifying the critical processes and their EEG correlates.

To argue functionality of Recognition Unit, it is necessary to employ the indices that can legitimately distinguish activity increase from decrease. The EEG data mining methods proposed by Delorme and Makeig (2004) is a good approach to disambiguate ERP results. According to these authors, scalp recorded EEG is the summation of activities from distributed cortical patches. In order to disentangle the scalp recorded EEG, independent component analysis (ICA, Bell and Sejnowski, 1995) provides an effective solution. ICA is also known as blind source separation (BSS), for it calculates an unmixing matrix in a fully data-driven manner. ICA is one of algorithms that find a solution to minimize the information redundancy across scalp channels. In conventional scalp EEG data, spatially adjacent electrodes usually show highly correlated wave patterns: this is what is called redundancy here. After the unmixing process, newly created independent components (ICs) are mutually maximally independent because their higher (more than 3) order correlations are minimized (usually to near-zero). It means that if one IC captures electrooculogram (EOG) from a left eye, then the remaining other ICs are free from EOG. This is not only useful in artifact rejection, but also effective in exploiting information from data. The IC activity refers to data transformed into the source space, which theoretically represents the direct neural activity. ICA is necessary in this experiment to specifically focus on N170-N250 complex in the ventral stream to maximize data reliability.

Another important solution to this experiment is the wavelet transform invented by Morlet and Grossman around 1981. This calculation allows decomposition of a given waveform into amplitude and phase, each of which is resolved with time and frequency scales. The virtue of this analysis is that it dissociates amplitude modulation from phase modulation, each of which represents different neural activity (e.g. Makeig et al., 2002; see Figure 1.5).

The amplitude modulation concerns the neural population that fires, while the phase modulation is related to temporal coordination of neural activity triggered by sensory input. This separation is important because these directly concerns mechanism of activity in the targeted local neural ensembles. The wavelet transform is applicable to IC-decomposed data, and effectiveness of this application on EEG data analysis is established (information-based

EED modeling, Onton and Makeig, 2006).

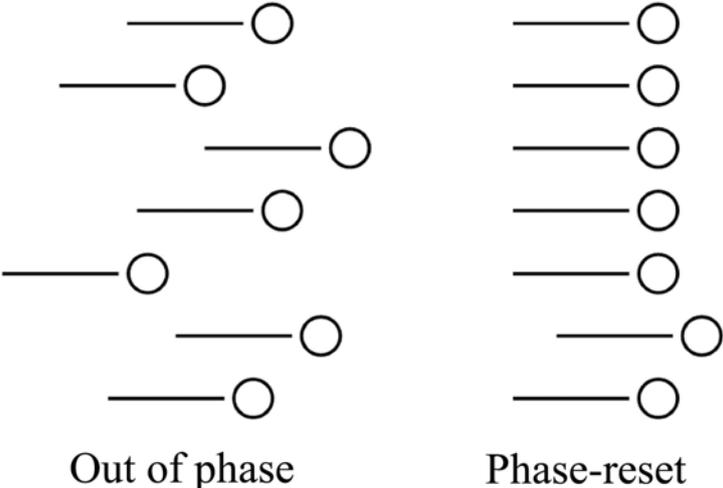


Figure 1.5 A schematic illustration of phase-resetting. Each circle in the figure represents EEG phase for every trial. The horizontal axis represents temporal flow, and the vertical axis represents trials. Note that this phase-resetting is a result of temporal coordination of neural firing and independent of increase in the population of firing neurons.

## Chapter 2

### *Domain generality of Recognition Unit (Experiment 1)<sup>1</sup>*

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#### *2.1 Introduction*

Our own property is unmistakably distinguished from other objects, just as our own names and faces are. This salience may indicate preferential recognition for self-relevant information. Several ERP studies were dedicated for visual self-recognition (Gray et al., 2004; Ninomiya et al., 1998; Tanaka et al., 2006) which provided evidence that allows to examine the time-course of this process, but little attention has been paid to self-relevant object recognition. Previous ERP studies demonstrated that self-face is associated with augmented N250 (Caharel et al., 2002; Tanaka et al., 2006), but it remains unclear whether this is also the case for self-relevant object recognition. The purpose of the first experiment is to clarify the response of Recognition Unit to self-relevant objects by measuring N250.

There were three experimental conditions: self-relevant, familiar, and unfamiliar. This is designed to distinguish self-relevance from less self-relevant familiarity. This approach is in line with recent face recognition studies (Caharel et al., 2002; Herzmann et al., 2004; Kircher et al., 2000, 2001; Platek et al., 2004b, 2006; Sugiura et al., 2005a; Tanaka et al., 2006; Uddin et al., 2005). In accordance with these studies, self-relevant objects were compared to less-self-relevant familiar objects, which were defined as pre-experimentally known but not belonging to the participants.

We adopted three ERP components as psychophysiological indices: N170 as the index of the Structural Coding, N250 as the index of Recognition Unit, and P300 as the index of higher order cognitive functions. The main interest in this study is to observe N250 modulation. If it shows negative deflation just like responses to self-face, it suggests domain-general property of Recognition Unit. If it does not distinguish self-relevance from familiarity, then it supports the possibility that Recognition Unit is domain-specific.

#### *2.2 Materials and Methods*

##### *2.2.1 Participants*

Eighteen right-handed healthy undergraduate students of Nagoya University participated in

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<sup>1</sup> Data in this study were published in: Miyakoshi M., Nomura, M., Ohira, H., 2007. An ERP study on self-relevant object recognition. *Brain and Cognition* 63, 182-189.

the experiment (mean 20.0 years, range 19-24, 13 women). Informed consent was obtained from all the participants. All participants reported normal or corrected-to-normal vision.

### *2.2.2 Stimuli*

Four kinds of objects served as stimuli: an umbrella, shoes, a cup, and a bag. For each object category, three levels of Familiarity were prepared: personally familiar objects belonging to participants (Self); unowned objects of frequently encountered types, instances of which participants had seen and used before (Familiar); and previously unseen objects belonging to someone else (Unfamiliar). For preparation of self-relevance stimuli, participants were asked to bring their own umbrella, shoes, cup, and bag. Those who did not possess all of these four items were initially excluded from the study. For familiar stimuli, a disposable umbrella, slippers, a paper cup, and a paper bag were chosen, all of which is commonly encountered varieties. Unfamiliar stimuli were chosen from objects belonging to other participants of the same sex, unless the objects were considered to be popular (e.g. products of famous brands). All items were photographed with a digital camera, and the photos were processed on a PC with Adobe Illustrator 8.0J. The backgrounds of all the photos were removed, and the clipped-out objects were pasted in the center of a gray background (Figure 2.1). All the stimuli were presented in natural color on a PC monitor. The visual angle of the stimuli was 9-12°. In order to confirm the participants' familiarity with the stimuli, after the experiment, participants were asked to complete questionnaires about how long and how many times they had used or seen the objects. A mean period of using objects presented as Self was  $2.6 \pm 2.8$  (mean $\pm$ SD) years. Of familiar objects, 44 out of 68 (for 17 participants, four objects each) answers indicated having seen the object more than 10 times a year, and the mean of the rest was 5.9 times a year. About the previous experience of using them, 21 out of 68 answers indicated more than 10 times a year, and the mean of the rest was 4.8 times a year. All participants answered that they had seen or used any object in the familiar category. It was also confirmed that none of the participants was familiar with the Unfamiliar objects.

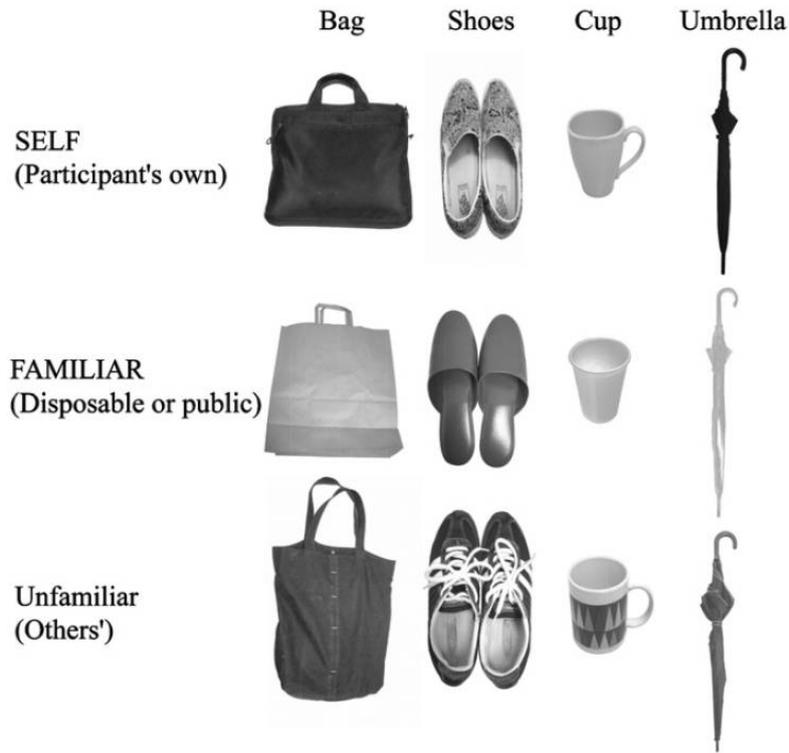


Figure 2.1 Examples of stimuli presented in the present experiment.

### 2.2.3 Task Design

In one block, two stimuli of the same Familiarity were presented in randomized order, and each of them was presented 40 times. One block was composed of 80 trials. Two blocks were assigned for each Familiarity. Each participant underwent a total of six blocks and 480 trials. The orders of the blocks and the sorts of objects were randomized across participants.

### 2.2.4 Procedure

In an electrically shielded and sound-attenuated dark chamber, a participant was comfortably seated at a distance of 90 cm from the CRT monitor. During the task, a white fixation cross was presented for 1500ms at the center of the display. It was replaced by a red fixation cross that was presented for 1500ms, during which eye blink was prohibited. Then, the visual stimulus was presented for 800ms. The flow of a trial is illustrated in Figure 2.2. Between blocks, several minutes of rest were taken appropriately. The participants' task was to observe the stimuli carefully and to answer questions about presented stimuli by describing them in detail during the rest period. All the participants could describe the presented stimuli correctly.

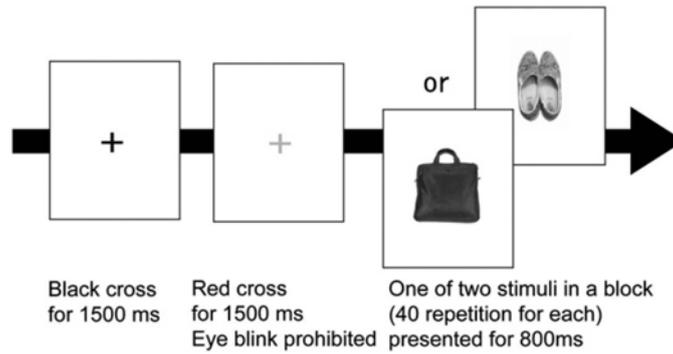


Figure 2.2 The flow of a trial. The participant's task was to observe the stimuli carefully so that during the rest period they could describe the stimuli correctly.

### 2.2.5 Electroencephalogram (EEG) Recording and Processing

EEG was recorded with BIOPAC (Goleta, CA) MP100 16 EEG recording units from 15 sites by using Ag/AgCl electrodes: the sites were Fz, F3, F4, F7, F8, Cz, C3, C4, T7, T8, Pz, P3, P4, P7, and P8, according to international 10-20 system. Reference electrodes were initially placed on the earlobes, and later the average reference was calculated. Electrooculogram (EOG) was monitored at the electrodes on the canthus and lower orbital ridge of the left eye. Impedance was kept below 10 k $\Omega$ , and typically below 5 k $\Omega$ . Signals were recorded with a 0.1Hz high-pass filter (6 dB/Oct) and 100Hz low-pass filter (18 dB/Oct). The sampling rate was 500Hz with a 16-bit A/D conversion.

EEG data analysis was performed using EEGLAB 5.02 (Delorme & Makeig, 2004; <http://www.sccn.ucsd.edu/eeglab>) running under Matlab 7.1 (The Mathworks). EEG of correctly responded trials was segmented to obtain epochs starting from 300ms before the stimulus onset until 1000ms after stimulus (baseline -300 to -50ms). All trials were inspected visually, and only artifact-free trials were retained. Epochs containing physiological and stereotyped artifacts such as eye blinks and heart beats were remained for later correction using independent component analysis (ICA). The mean percentage of rejected epochs was 25.4% (range: 0–37.5%). Next, individual concatenated single-trial data-sets were decomposed with Infomax ICA. Sixteen components were derived from each subject's data. Components representing artifacts were identified and rejected from further analysis by visual inspection of individual component properties. A mean of three independent components (range: 1–6) were identified and rejected by analyzing the scalp topography, the component ERP, the component power spectrum, and the component ERP-image. Then, artifact-free EEG data were obtained by back-projecting the remaining non-artifactual ICA components to scalp

EEG, by multiplying the selected component activities with the reduced component mixing matrix. The EEG was low-pass filtered at 20Hz with a finite impulse response (FIR) filter. The EEG was recalculated to an average reference excluding the EOG channel. ERPs were calculated independently for each channel and condition by averaging trials belonging to same conditions. Average amplitudes of N170, N250, and P300 were calculated. The peak latencies of N170 at P7 and P8 served as the center of the time window. The time window of N170 was defined to be 140-180ms poststimulus; N250 was defined to be 200-300ms; and P300 was defined to be 300-700ms poststimulus.

### *2.2.6 Statistical Analysis*

Mean amplitudes of N170, N250, and P300 were submitted to 3 (Familiarity: Self, Familiar, Unfamiliar) x 15 (Electrode: Fz, F3, F4, F7, F8, Cz, C3, C4, T7, T8, Pz, P3, P4, P7, and P8) two-way repeated measures ANOVAs. For the purpose of confirmation, N170 lateralization at P7 and P8 was tested by 3 (Familiarity: Self, Familiar, and Unfamiliar) x 2 (Laterality: P7, P8) two-way repeated measures ANOVAs. The Greenhouse–Geisser correction was applied wherever necessary. For post hoc multiple comparisons, the Bonferroni correction was used with a significance level of .05.

### *2.3 Results*

Figure 2.3 shows the grand mean ERP for all the scalp electrodes in all the conditions. Figure 2.4 shows the results of multiple comparisons with scalp electrode locations.

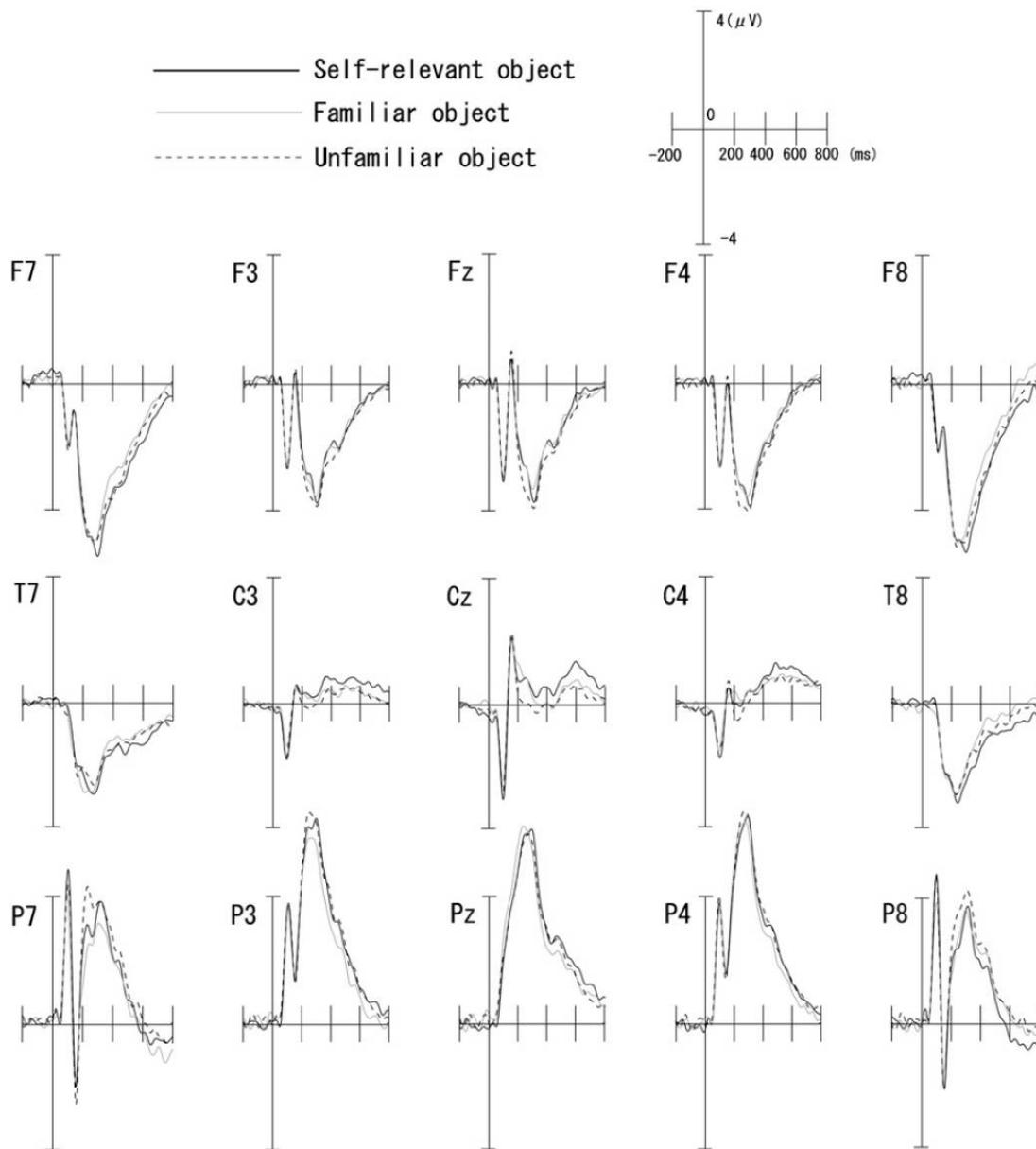


Figure 2.3 Grand mean ERPs for Self, Familiar, and Unfamiliar object recognition.

### 2.3.1 N170

The results of the ANOVAs did not show a significant interaction Familiarity x ELECTRODE,  $F(28, 504) < 1$ . For confirmation, post hoc multiple comparisons were performed, but no significant difference was found in any electrodes across any combination of Familiarity. The results did not observe familiarity effect on N170. The two-way ANOVAs Familiarity x ELECTRODE (P7 and P8) did not reveal significant main effect of ELECTRODE,  $F(1, 18) < 1$ ; Familiarity,  $F(2, 36) < 1$ ; or the interaction,  $F(2, 36) < 1$ . The results failed to observe the effect of lateralization either.

### 2.3.2 N250

The results of the ANOVAs showed a significant interaction Familiarity x Electrode,  $F(28, 504) = 2.9, P < 0.05$ . In order to test the interaction, post hoc multiple comparisons were performed. The results are shown in Figure 2.4. Significant differences between Self and Unfamiliar were found at electrodes Cz and P7, and between Familiar and Unfamiliar at Fz, Cz, C4, P7 (all  $P < 0.05$ ). Thus Self and Familiar were both dissociated from Unfamiliar. However, the results did not find statistically significant difference between Self and Familiar at any electrode. The results indicate that N250 dissociate only familiarity in object recognition, and sensitivity to self-relevance to objects was not confirmed.

### 2.3.3 P300

The results of ANOVAs showed significant interaction Familiarity x Electrode,  $F(28, 504) = 2.4, P < 0.05$ . Post hoc multiple comparisons revealed significant differences between Self and Unfamiliar at Cz; between Familiar and Unfamiliar at P3; and importantly, between Self and Familiar at F7, T8, and P3 (all  $P < 0.05$ ). These results are shown in Figure 2.4. The results suggest that self-relevance with objects was dissociated in the cognitive process whose time-course begins 300ms after stimulus presentation.

## 2.4 Discussion

The purpose of this experiment is to clarify the response of Recognition Unit to self-relevant objects by measuring N250. Details of the findings are addressed below.

### 2.4.1 Domain-dependent response of Recognition Unit

The N250 modulation was observed in the results from this experiment, which confirmed dissociation of object familiarity, including self-relevance, from unfamiliar objects. This N250 response could be reflection of already existing stored representations of familiar objects in harmony with conclusions of previous familiar face recognition studies (Pfützte et al., 2002; Schweinberger et al., 2002a; Schweinberger et al., 2004). Nonetheless, self-relevance was not reflected, which is the critical finding in this study. This is in contrast with self-face recognition studies that examined N250 (Caharel et al., 2002, 2005; Tanaka et al., 2006). The discrepancy strongly suggests the differentiated mechanism depending on object domains in

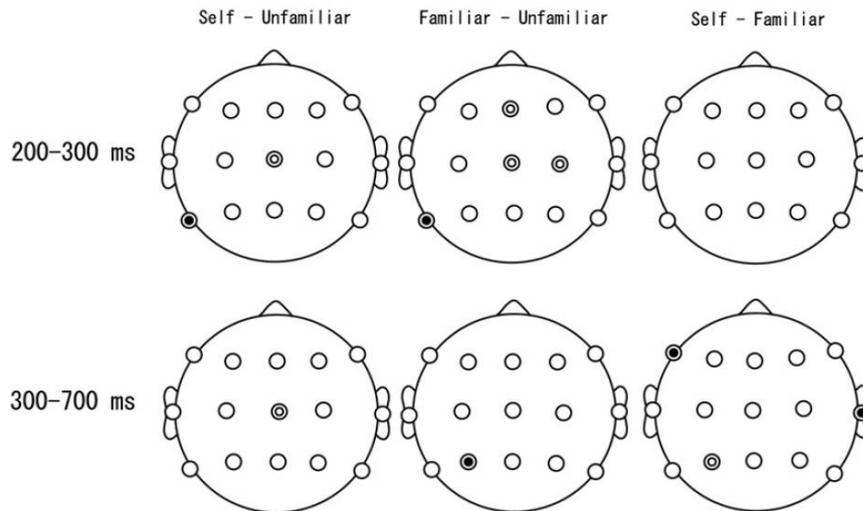


Figure 2.4 The results of multiple comparisons on N250 (200–300ms, top row) and P300 (300–700ms, bottom row) across Familiarity (columns). Single circles show non-significant results in multiple comparisons; concentric double circles show significantly positive difference; and single circles with concentric solid black circle show significantly negative difference, in respective contrasts.

occipito-temporal areas. The results support the distinction of domains in the Bruce and Young model (1986).

The domain-dependent nature of Recognition Unit indicates different onset in the time-course of visual self-recognition. If self-relevance is not distinguished in this stage for objects, it suggests relative priority of self-face recognition compared to objects. The results from the present study showed that self-relevance with objects were dissociated only after 300ms poststimulus, which is more than 100ms delayed compared to self-face recognition. Together with ERP literature of self-face recognition, the present results support the view that recognition of self-relevant objects is not as prioritized as that of self-face.

#### 2.4.2 Lateralization of N250

The N250 modulation for objects was observed in left occipitotemporal electrode and not in the opposite hemisphere. The result thus suggests the left lateralization for this process. Evidence of left-lateralized processes in familiarity recognition were reported in literature. For example, Nessler et al. (2005) found most likely N250-homologue that differentiated familiar–famous faces from unfamiliar faces at left occipitotemporal, left frontal, and central electrodes, while it was not found over right hemisphere. Evidence was also provided by brain imaging studies. Gorno-Tempini et al. (1998) reported brain activity related to domain-general

familiarity, which was familiar–famous across faces and names, in the region from left anterior temporal to left temporo-parietal cortex. Importantly, Gorno-Tempini and Price (2001) later found left lateralized brain activity involved in domain-general familiarity (familiar–famous) across faces and buildings in the left middle temporal gyrus. Evidence of familiarity-related processes was also found in left fusiform gyrus in familiar–famous face recognition (Eger et al., 2005; Pourtois et al., 2005) as well as the left medial temporal region in familiar–intimate face recognition (Sugiura et al., 2001). Current source estimation analysis on N250 showed that it is originated within fusiform gyri (Schweinberger et al., 2002a). Taken together, results from the present study may suggest that the left fusiform gyrus is involved in processes of object familiarity within the time course of 200–300ms after stimulus onset.

In contrast to N250, N170 did not reveal any significant main effect or interaction, suggesting that familiarity with objects did not affect processes involved in Structural Coding. The result is in line with literature of N170 (Pfütze et al., 2002; Schweinberger et al., 2002a). In terms of N170 lateralization, although previous face recognition studies have commonly reported a larger N170 over the right hemisphere (Bentin et al., 1996; Eimer, 1998; Itier & Taylor, 2004; Rossion et al., 2002; Schweinberger et al., 2004), it was not observed in our results. This suggests differentiated mechanisms involved between face and object recognition in Structural Coding.

#### *2.4.3 Distinction of Self-relevance in the later time-course*

P300 dissociated self-relevance from familiarity. The late component is considered to indicate involvement of higher-order cognitive functions, either it is P300 or N400 (for P300 evidence, Farwell and Donchin, 1991; Johnston et al., 1986; Johnston and Wang, 1991; Nasman and Rosenfeld, 1990; for N400 evidence, Pfütze et al., 2002; Pickering and Schweinberger, 2003; Schweinberger et al., 2002a). It is in harmony with the traditional idea that distinguishing self-relevance from less-self-relevant familiarity requires higher-order functions (Berlad and Pratt, 1995; Fischler et al., 1987; Folmer and Yingling, 1997; Gray et al., 2004; Müller and Kutas, 1996; Ninomiya et al., 1998; Perrin et al., 1999, 2005; but see Caharel et al., 2002; Tanaka et al., 2006). The results from the present study showed that involvement of the higher-order cognitive functions is invariable irrespective of stimulus domains. However, it should be noted that the results in the present study did not show clear P300 peak amplitude modulation, although P300 itself was present. This may be due to passive viewing design which was originally adopted by Caharel et al. (2002). According to an fMRI study on this

effect, self-relevant recognition tasks with active response not only engage response-related brain regions but also enhance activation in regions recruited in self-relevant processing (Sugiura et al., 2000). Self-relevant cognitive functionality may have been engaged relatively less than the active tasks.

#### *2.4.4 Conclusion*

N250 did not dissociate self-relevance from non-self-relevant familiarity in object recognition. The result is in the clear contrast with the case of self-face recognition. The discrepancy strongly suggests domain-dependency of Recognition Unit in visual self-relevance recognition. Together with previous studies, the result from the present study supports the conclusion that the process of detecting self-relevance in visual recognition differs depending on stimulus domain. This conclusion is in harmony with the Bruce and Young model, in which different models are proposed for face recognition and object recognition.

## Chapter 3

### *Represented familiarity in Recognition Unit (Experiment 2)<sup>2</sup>*

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#### *3.1 Introduction*

The question whether self-relevance represented by Recognition Unit is perceptual or abstract remains unclear. Schweinberger et al. (2002a) reported that the immediate priming effect by facial identities was effective even across different facial views, but only when the presented faces were familiar (Schweinberger et al., 2002a). The finding supports the possibility that Recognition Unit processes beyond-perceptual representation. However, there is no direct evidence that visual representation of self-relevance is also represented in the similar manner. A behavioral study conducted by Troje and Kersten (1999) actually provided the opposite results. The key invention in their design is to show one's own profile (i.e. 90 degree axially rotated faces) to participants. It should be perceptually non-fluent because it can not be seen with a simple mirror, but should be semantically familiar because it is self-relevant. They reported that differences in RTs to detect one's own profile and frontal view were much larger in self than in familiar faces. They concluded that facial familiarity is viewpoint-dependent, and is related to perceptual fluency rather than semantic familiarity. Although this conclusion does not have immediate reference to Recognition Unit, the result seems to require replication with ERP recordings to observe viewpoint variance effect on N250 to determine if the represented self-relevance is perceptual or semantic.

In order to clarify the nature of represented familiarity by Recognition Unit, the second ERP study was designed. Two facial angles (Angle: Frontal and Profile) and three levels of familiarity (Familiarity: one's own, Self; Famous; and Unfamiliar) were prepared as stimulus categories. Reaction times served as an index of task performance, and three ERP components, N170, N250, and P300 served as indices of Structural Coding, Recognition Unit, and higher-order semantic processes.

#### *3.2 Materials and Methods*

##### *3.2.1 Participants*

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<sup>2</sup> Data in this study were published in: Miyakoshi, M., Kanayama, N., Nomura, M., Iidaka, T., Ohira, H., 2008. ERP study of viewpoint-independence in familiar-face recognition. *International Journal of Psychophysiology* 69, 119-126.

Participants were 16 right-handed healthy undergraduate students (mean age 20.4 years, range 18–21 years; 10 women). Informed consent was obtained from all participants. All experimental processes were carried out based on Declaration of Helsinki. All participants reported that they were right handed and had normal or corrected-to-normal vision.

### *3.2.2 Stimuli*

Facial images with three levels of Familiarity (one's own face, Self; famous person's face, Famous; and unfamiliar other's face, Unfamiliar) and two levels of Angle (a frontal view, Frontal; and a right-profile view, Profile) were prepared. Before the experiment, participants' faces were photographed with a digital camera. As the famous person, the former Japanese Prime Minister (Junichirou Koizumi) was selected. Frontal and profile views of his face were collected from Internet websites. Facial images of Unfamiliar were chosen from the other participants' Self with the same sex. All facial images showed a neutral expression. Digital pictures were processed to remove the background and everything below the neck, and then converted into grayscale. These images were resized so that the visual angle was  $4 \times 5^\circ$ .

### *3.2.3. Experimental procedure*

During the experiment, a participant was comfortably seated in a dimly lit, sound-attenuated, and electrically shielded room. All stimuli were presented on a CRT monitor, and the distance from the participant was 90 cm. There were two blocks in the experiment across which the condition Angle was tested. Within a block, three levels of Familiarity were compared. The presentation order was randomized. The time course for each trial was as follows: a white fixation cross for 1500 ms, a red fixation cross for 1500 ms during which eye blinks were prohibited, and the stimulus for 800 ms. Participants were instructed to press one of three keys assigned to the index, middle, and ring fingers of the right hand, respectively, to judge the levels of Familiarity as quickly and accurately as possible. Reaction times were measured as the behavioral index. The order of blocks and the key assignment were counterbalanced across participants. Each stimulus was presented 50 times. One experiment was composed of total of 300 trials. There was a rest period between blocks appropriately.

### *3.2.4 EEG recording*

EEG was recorded with BIOPAC (Goleta, CA) MP100 16-channel EEG recording unit. EEG

signals were recorded with a 0.1 Hz high-pass filter (6 dB/oct) and a 100 Hz low-pass filter (18 dB/oct). The sampling rate was 500 Hz. The resolution of A/D conversion was 16 bit. Ag/AgCl electrodes were placed on 15 scalp sites: Fz, F3, F4, F7, F8, Cz, C3, C4, T7, T8, Pz, P3, P4, P7 and P8 according to the international 10–20 system. EOG was monitored from AFp9 which is approximately the outer canthus of the left eye. All electrode impedance was kept below 10 k $\Omega$ , and typically below 5 k $\Omega$ . EEG electrodes were initially referenced to earlobes, and an average reference was computed later.

### *3.2.5 EEG analysis*

EEG data analysis was performed using EEGLAB 5.02 (Delorme & Makeig, 2004; <http://www.sccn.ucsd.edu/eeglab>) running under Matlab 7.2 (The Mathworks). Continuous EEG data were segmented into epochs starting 1000 ms prior to and 2000 ms following stimulus onset (baseline –200 ms to 0 ms). EEG data of correctly responded trials were included in the dataset. The range of accepted RTs was set to 200-1600ms after stimulus onset within which all recorded responses fell. A 1 Hz high-pass FIR filter was applied to EEG data to remove a linear trend to stabilize later independent component analysis (ICA). For noise rejection, all epochs were first visually inspected to discard trials with irregular noise. Typical artifacts such as eye blinks, eye movement, or muscle artifacts were kept for later ICA. At this stage, a mean of 6.3% (range 2.3%–13.0%) of trials were discarded. An extended infomax ICA (implemented in EEGLAB) was then performed for each dataset. A mean of 1.9 (range 1 to 5) out of 16 components were identified as representing either ocular activity, muscle potential, or heart beat, based on an inspection of frequency spectra, averaged ERP, single-trial ERP image and scalp topography. These components were rejected, and the remaining components were backprojected to compose artifact-free EEG. Averaged ERPs were then calculated for each participant and condition. The time windows of ERP components were as following: for N170, 150 ms–200 ms; for N250, 200 ms–300 ms; for P300, 300 ms–500 ms. They were defined by inspecting grand-average ERP peaks of the present data at P7 and P8 for N170 and N250 and at Pz for P300 where they showed maximal amplitudes.

### *3.2.6 Statistical tests*

Mean RTs of all trials were tested by two-way repeated measures analysis of variance with the factors Angle (Frontal, Profile) x Familiarity (Self, Famous, Unfamiliar). For the ERP

components, N170 amplitude and peak latency and N250 amplitude were measured at bilateral occipitotemporal sites (P7, Left; P8, Right). Three-way repeated measures analysis of variance was performed on them with the factors Angle (Frontal, Profile) x Familiarity (Self, Famous, Unfamiliar) x Laterality (P7, P8). P300 amplitude and latency were measured at Pz and tested with two-way repeated measures analysis of variance with the factors Angle (Frontal, Profile) x Familiarity (Self, Famous, Unfamiliar). For peak latency tests, one dataset was excluded because the N170 peak was not clear. In performing ANOVAs, the Greenhouse–Geisser correction was applied wherever necessary. The correction coefficient  $\epsilon$  is shown when applied. When the main effect or interaction was significant, post hoc multiple comparisons were performed with the Bonferroni correction. The significant level was set to 0.05.

### 3.3 Results

Figure 3.1, Figure 3.2, and Figure 3.3 show grand-average ERP plots from –200 to 800 ms comparing Frontal to Profile for each level of Familiarity at all recorded channels. For plotting purpose, 20 Hz low-pass FIR filter was applied.

#### 3.3.1 RTs

Table 1.1 shows RTs for each combination of conditions. The interaction Angle vs. Familiarity did not show significant interaction,  $F(2, 30) < 1$ . The results did not replicate the previously reported Angle vs. Familiarity interaction (Troje and Kersten, 1999). Subsequently, main effects were tested. The RT for Frontal ( $M=482.1$  ms,  $SE=13.3$ ) was significantly shorter than RT for Profile ( $M=504.0$  ms,  $SE=14.6$ ),  $F(1, 15) = 10.9$ ,  $P < 0.005$ ,  $\eta^2=0.871$ . This result suggests cognitive fluency for Frontal over Profile. The RTs for three levels of Familiarity were as follows: Self ( $M=469.8$  ms,  $SE=13.4$ ), Famous, ( $M=498.9$  ms,  $SE=15.5$ ), and Unfamiliar ( $M=510.5$  ms,  $SE=14.2$ ). The main effect of Familiarity was significant,  $F(2, 30) = 12.7$ ,  $P < 0.001$ ,  $\eta^2=0.994$ . Post hoc multiple comparisons revealed that Self was significantly shorter than both Famous ( $P < 0.005$ ) and Unfamiliar ( $P < 0.005$ ) while the difference between Famous and Unfamiliar was not significant ( $P=0.54$ ). The results suggest the advantage of self-relevance over the other two levels of familiarity.

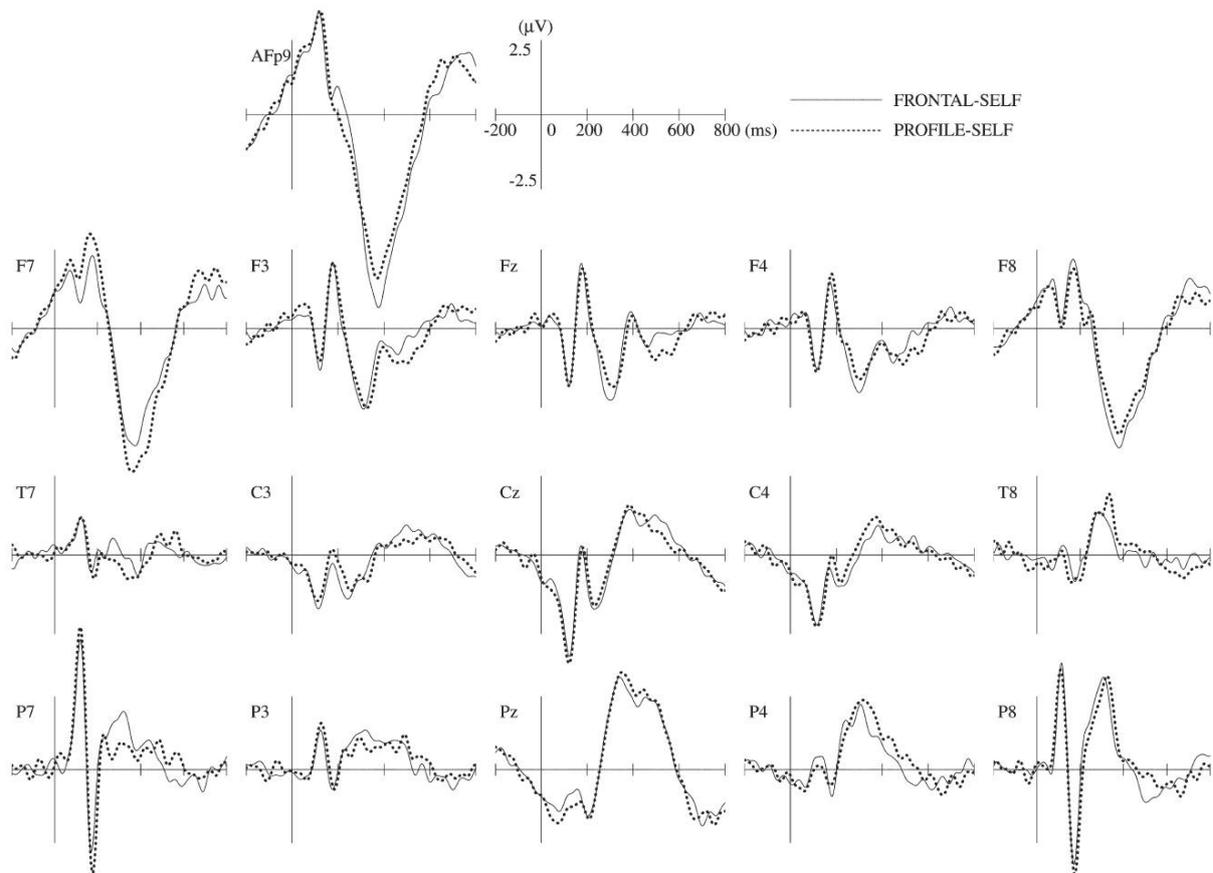


Figure 3.1 Grand mean ERPs for Frontal and Profile of one's own face (Self).

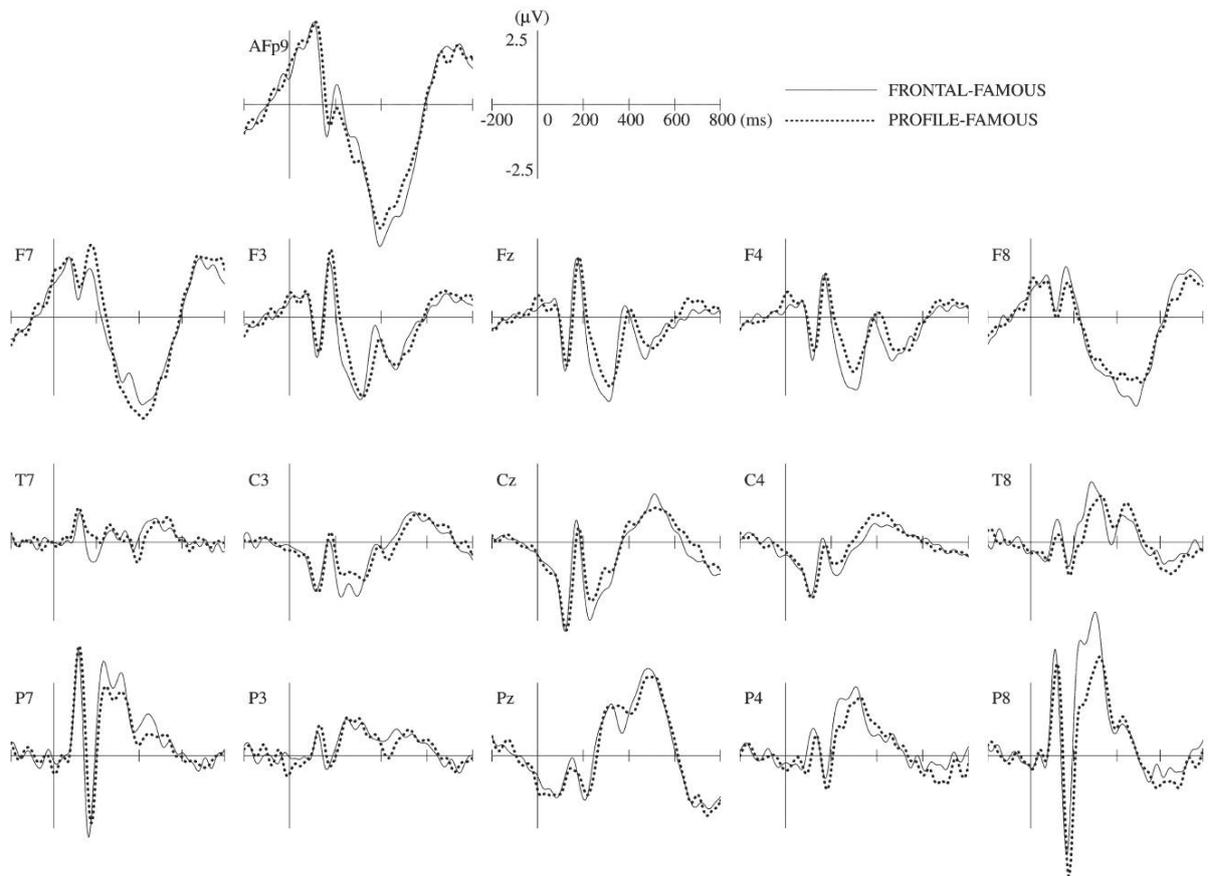


Figure 3.2 Grand mean ERPs for Frontal and Profile of famous person's face (Famous).

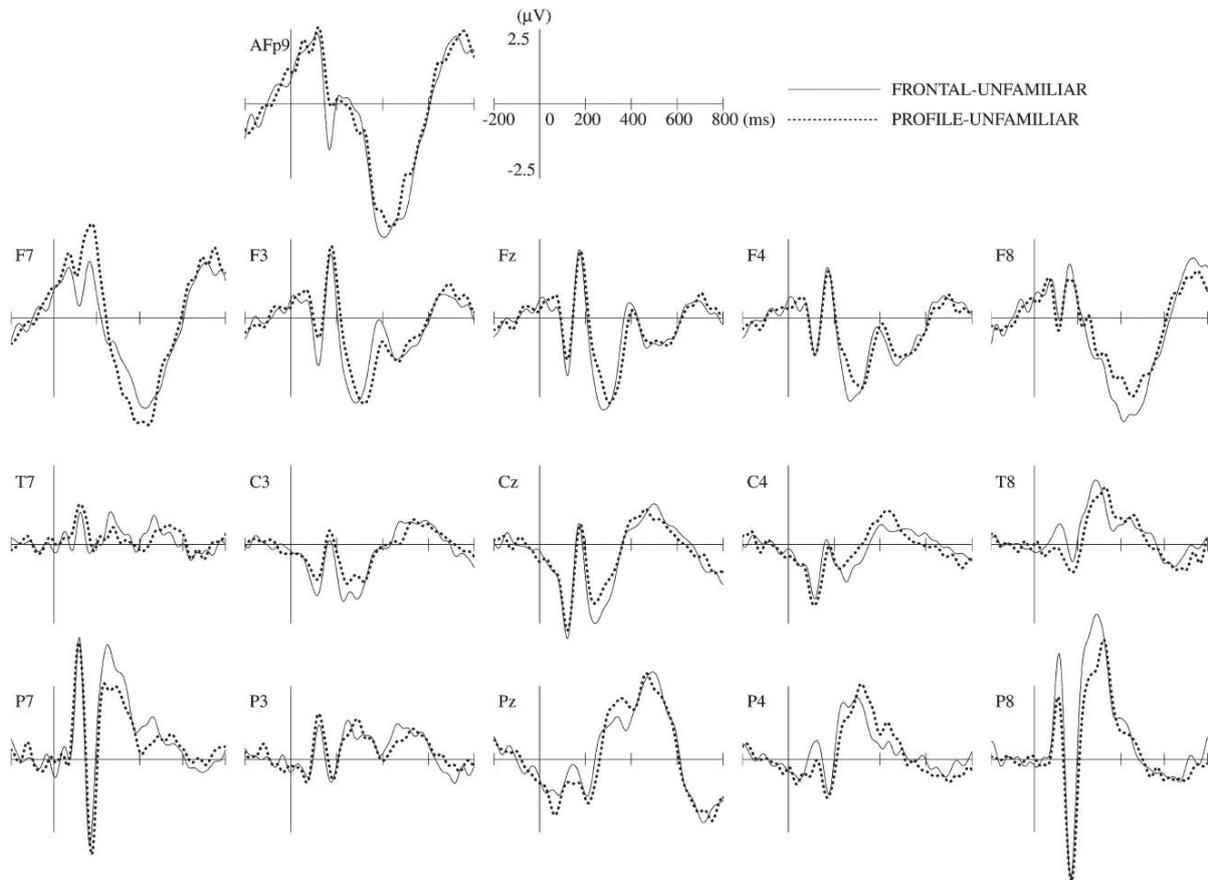


Figure 3.3 Grand mean ERPs for Frontal and Profile of an unfamiliar face (Unfamiliar).

Table 1.1

Mean reaction times (ms) with standard errors.

RTs	Frontal	Profile
Self	458.8 (13.5)	480.8 (14.3)
Famous	488.4 (15.4)	509.5 (16.1)
Unfamiliar	499.1 (14.3)	521.8 (15.7)

The main effects Angle and Familiarity were significant.

### 3.3.2 N170

Table 1.2 shows N170 amplitude and peak latency. For amplitude analysis, neither Angle vs. Familiarity vs. Laterality nor Angle vs. Familiarity showed significant interaction,  $F(2, 30) = 1.50$ ,  $P = 0.239$ ;  $F(2, 30) < 1$ , respectively. N170 amplitude did not reflect the Angle difference affected by Familiarity. The main effect of Angle was then tested. Frontal ( $M = -2.03\mu V$ ,  $SE = 0.60$ ) was slightly more positive than Profile ( $M = -2.4\mu V$ ,  $SE = 0.68$ ), but the difference was not significant,  $F(1, 15) = 2.03$ ,  $P = 0.175$ . Thus, the reliable Angle

difference was not found. N170 for the three levels of Familiarity was tested: Self ( $M=-2.24\mu\text{V}$ ,  $SE=0.62$ ), Famous ( $M=-1.94\mu\text{V}$ ,  $SE=0.64$ ), and Unfamiliar ( $M=-2.44\mu\text{V}$ ,  $SE=0.68$ ). The differences were not significant,  $F(2, 30) = 2.37$ ,  $P = 0.111$ . These results suggest that levels of Familiarity were not reflected in N170 amplitude.

For peak latency analyses, while three-way interaction was not significant,  $F(2, 28) < 1$ , the interaction Familiarity vs. Angle was significant,  $F(2, 28) = 9.79$ ,  $P < 0.001$ ,  $\eta^2 = 0.412$ . Post hoc multiple comparisons revealed that an Angle difference was present for Self and Famous but not clear for Unfamiliar: for Self, Frontal ( $M=166.1\text{ms}$ ,  $SE=3.5$ ) vs. Profile ( $M=176.5\text{ms}$ ,  $SE=3.7$ ),  $P < 0.001$ ; for Famous, Frontal ( $M=166.4\text{ms}$ ,  $SE=3.1$ ) vs. Profile ( $M=171.6\text{ms}$ ,  $SE=3.2$ ),  $P < 0.05$ ; for Unfamiliar, Frontal ( $M=171.3\text{ms}$ ,  $SE=3.1$ ) vs. Profile ( $M=172.4\text{ms}$ ,  $SE=3.7$ ),  $P = 0.603$ . Thus, the N170 peak latency differentiated Angle differences of familiar faces, including one's own, from those of unfamiliar faces.

Table 1.2

N170 mean amplitudes ( $\mu\text{V}$ ) and latency (ms) respectively with standard errors.

N170	Sites	Frontal		Profile	
		Amplitude	Latency	Amplitude	Latency
Self	P7	-1.74 (0.80)	165.6 (3.2)	-2.25 (0.78)	178.3 (3.8)
	P8	-2.29 (0.59)	166.5 (4.0)	-2.70 (0.64)	174.7 (3.9)
Famous	P7	-1.68 (0.86)	168.8 (3.0)	-1.28 (0.97)	173.5 (4.9)
	P8	-2.08 (0.54)	164.0 (3.7)	-2.72 (0.64)	169.7 (3.6)
Unfamiliar	P7	-1.70 (0.99)	168.9 (3.5)	-2.07 (0.83)	171.6 (3.6)
	P8	-2.73 (0.45)	173.6 (3.8)	-3.27 (0.79)	173.3 (4.2)

Amplitude data did not show any significant main effect or interaction. Peak latency data showed significant interaction for Angle vs. Familiarity.

### 3.3.3 N250

The interaction Angle vs. Familiarity vs. Laterality was significant,  $F(2, 30) = 5.02$ ,  $P < 0.05$ ,  $\eta^2 = 0.251$ . The results of post hoc multiple comparisons with the Bonferroni correction are shown in Table 1.3 and Figure 3.4. The Angle difference was associated with N250 negativity, and was present for Self at Left, Famous at Right, and Unfamiliar at bilateral sites. Note that Angle difference for Self at Right and that for Famous at Left were attenuated to insignificance. The result suggests that decrease of an Angle difference may be due to viewpoint-independence in familiar faces. Furthermore, the attenuation of Angle difference

was observed in different laterality between Self and Famous.

In addition to these findings, ANOVAs also found the main effects of Angle. Frontal ( $M=2.70\mu\text{V}$ ,  $SE=0.56$ ) was more positive than Profile ( $M=1.56\mu\text{V}$ ,  $SE=0.70$ ), and the difference was significant,  $F(1, 15) = 11.59$ ,  $P < 0.005$ ,  $\eta^2 = 0.436$ . The main effect of Familiarity was also significant: Self ( $M=1.17\mu\text{V}$ ,  $SE=0.58$ ); Famous ( $M=2.45\mu\text{V}$ ,  $SE=0.61$ ); and Unfamiliar ( $M=2.76\mu\text{V}$ ,  $SE=0.68$ ). The differences were significant,  $F(2, 30) = 25.0$ ,  $P < 0.001$ ,  $\eta^2 = 0.625$ . Post hoc multiple comparison revealed that Self was significantly more negative than Famous and Unfamiliar (both  $P < 0.001$ ) while the difference between Famous and Unfamiliar was not significant ( $P = 0.233$ ).

Table 1.3

N250 mean amplitudes ( $\mu\text{V}$ ) with standard errors.

N250	Sites	Frontal	Profile	Difference
Self	P7	1.21 (0.68)	0.55 (0.82)	$P < 0.05$
	P8	1.76 (0.67)	1.15 (0.66)	<i>n.s.</i>
Famous	P7	2.52 (0.78)	1.78 (0.92)	<i>n.s.</i>
	P8	3.82 (0.82)	1.70 (0.85)	$P < 0.001$
Unfamiliar	P7	3.10 (0.92)	2.06 (0.86)	$P < 0.05$
	P8	3.78 (0.73)	2.12 (0.82)	$P < 0.01$

Three-way interaction was significant, and results of a Bonferroni-corrected multiple comparisons are shown.

### 3.3.4 P300

Table 1.4 shows P300 amplitudes and peak latencies for each combination of conditions. For the amplitude analysis, the interaction Angle vs. Familiarity was not significant,  $F(2, 30) = 0.73$ ,  $P = 0.49$ . The main effect of Angle was tested. Frontal ( $M=2.08$ ,  $SE=0.33$ ) was less positive than Profile ( $M=2.25$ ,  $SE=0.34$ ), but this difference was not significant,  $F(1, 15) = 0.773$ ,  $P = 0.39$ . P300 for the three levels of Familiarity was as follows: Self ( $M=2.66\mu\text{V}$ ,  $SE=0.40$ ), Famous ( $M=1.87\mu\text{V}$ ,  $SE=0.30$ ), and Unfamiliar ( $M=1.97\mu\text{V}$ ,  $SE=0.33$ ). The differences were significant:  $F(2, 30) = 8.76$ ,  $P < 0.005$ ,  $\epsilon = 0.625$ ,  $\eta^2 = 0.369$ . Post hoc multiple comparison revealed that Self was more positive than Famous and Unfamiliar ( $P < 0.01$  and  $P < 0.05$ , respectively) while the difference between Famous and Unfamiliar was not significant. The results confirmed that P300 is sensitive to self-relevance.

For the peak latency analysis, the interaction Angle vs. Familiarity was not significant,

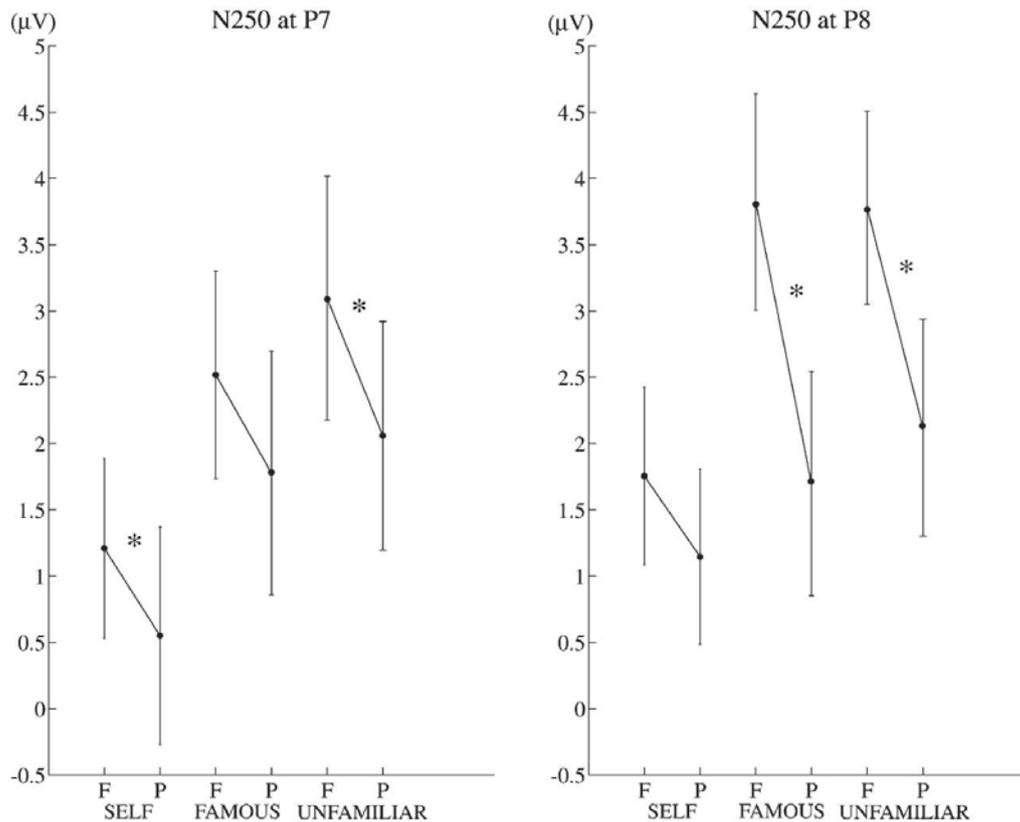


Figure 3.4 N250 comparison for Frontal vs. Profile at P7 (Left) and P8 (Right). Significant differences ( $P < 0.05$ ) in Bonferroni-corrected multiple comparisons are highlighted with asterisks (\*). F, frontal view; P, profile view.

Table 1.4

P300 mean amplitudes ( $\mu\text{V}$ ) and latency (ms) respectively with standard errors.

P300	Frontal		Profile	
	Amplitude	Latency	Amplitude	Latency
Self	2.56 (0.40)	418.3 (20.3)	2.76 (0.42)	388.5 (17.0)
Famous	1.87 (0.31)	454.5 (19.3)	1.87 (0.35)	439.7 (23.3)
Unfamiliar	1.80 (0.37)	451.6 (21.7)	2.13 (0.34)	443.7 (22.4)

Both amplitude and peak latency data showed the significant main effect of Familiarity.

$F(2, 28) = 0.341$ ,  $P = 0.714$ . The main effect of Angle was not significant: for Frontal,  $M=441.5$  ms,  $SE=16.4$ ; for Profile,  $M=424.0$  ms,  $SE=17.0$ ;  $F(1, 14) = 1.15$ ,  $P = 0.301$ . The main effect of Familiarity was significant; for Self,  $M=403.4$  ms,  $SE=16.7$ ; for Famous,  $M=447.1$  ms,  $SE=16.4$ ; for Unfamiliar,  $M=447.7$  ms,  $SE=19.2$ ;  $F(2, 28) = 4.63$ ,  $P < 0.05$ ,  $\eta^2 = 0.249$ . Although post hoc multiple comparison failed to detect a significant difference, the

order of P300 latency for each condition were in line with previous studies and showed shorter latency for Self than for Famous and Unfamiliar.

### *3.4. Discussion*

The purpose of the present study was to examine represented familiarity by Recognition Unit. For this purpose, N250 responses to frontal and profile view of self-face were compared. ERP results confirmed viewpoint-invariant representation of self-face, which suggests beyond-perceptual nature of the represented familiarity by Recognition Unit. The same was also confirmed for the famous face, but the ERP modulation was observed in the left hemisphere which is opposite to self-face. In addition, P300 also distinguished self-relevance.

The behavioral data showed prolonged RTs for Profile than for Frontal and confirmed advantage of perceptual fluency with frontal view of faces (Troje and Kersten, 1999). In face-matching tasks, it is known that profiles are associated with poor task performance (Hancock et al., 2000). Prolonged RTs in the present study is consistent with this view.

#### *3.4.1 Beyond-perceptual representation in Recognition Unit*

For unfamiliar faces, N250 differed across facial angles. It suggests perception dependency of Recognition Unit for unfamiliar faces. In other words, Recognition Unit may not recognize the two different views of the same person as identical. This serves as a baseline in interpreting the results of other familiar faces. Compared to this, facial angle effect on one's own and famous persons' faces were much diminished. It indicates immunity to view changes as long as the person identity is already stored and available for Recognition Unit. This supports the view of beyond-perceptual nature of the stored representations.

Note that it may seem contradictory that N250 showed response to profiles rather than frontal views. Our preferred interpretation is that N250 may have different sensitivity to both structural fluency regarding facial view angles and pre-experimental familiarity with the identity of the person represented by the face.

#### *3.4.2 N170 latency modulation in Angle vs Familiarity*

N170 peaks were delayed for Profile of Self and Famous but not for Unfamiliar. This may indicate the earliest stage of familiarity recognition in which, nonetheless, Self is not distinguished. This leads to the speculation that facial familiarity affects the process of

Structural Coding. Note that N170 amplitude modulation was not observed in the present study, which is consistent with previous reports (Eimer, 2000; for VPP study, Jeffreys et al., 1992; see Joyce and Rossion, 2005). For familiar faces, frontal views, which were more canonical than profiles (Troje and Kersten, 1999), were associated with earlier N170. The result suggests perceptual preference in Structural Coding. The earlier N170 may be evidence of facilitation of process speed in the ventral stream.

### *3.4.3 Self-relevance and familiarity represented by hemispheric lateralization*

N250 modulation was diminished for one's own and famous persons' faces in different hemispheres. Most behavioral and fMRI studies have related self-relevance processes to the right hemisphere (Keenan et al., 1999, 2000a, 2001; Platek et al., 2004b; Sugiura et al., 2005a; Uddin et al., 2005; for review, Keenan et al., 2000b; Van Lancker, 1991). Consistent with these reports, the results from the present study indicated lateralization to the right in the viewpoint-invariant process for one's own face. On the other hand, domain-general familiarity has been associated with left temporal lobe activation by fMRI studies (Gorno-Tempini and Price, 2001; Gorno-Tempini et al., 1998). There is ERP study that reported N250-homologue in the left hemisphere that was associated with facial familiarity (Nessler et al., 2005). fMRI studies also associated viewpoint-invariant familiar face recognition with the left anterior fusiform gyrus activation (Eger et al., 2005) and left middle temporal gyrus (Pourtois et al., 2005). These findings are consistent with the attenuation of an Angle difference in the left hemisphere in the present study.

### *3.4.4 Conclusion*

The results from the present study support the view that stored representation available in Recognition Unit is abstract and rather semantic than perceptual. It suggests beyond-perceptual nature of the represented familiarity. This excludes the possibility that visual self-relevance is mere perceptual fluency.

## Chapter 4

### *Mechanism issue (Experiment 3)*<sup>3</sup>

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#### *4.1 Introduction*

In Experiment 1 and Experiment 2, the natures of Recognition Unit were determined to be domain-dependent and beyond-perceptual. There remains one final question, which is about its mechanism. The functional role of Recognition Unit is assumed to be ‘matching the input information with the stored representation’, but this explanation provides only figurative understanding. This explanation does not contradict with empirical evidence, but does not provide a critical constraint, either. In other words, the matching model fulfills only the sufficient condition, not the necessary condition. The critical question that determines the direction of the research in the Experiment 3 is how the functionality of Recognition Unit is represented and mediated by the neural mechanism. Thus, the primary purpose in this study is to determine possible mechanism of Recognition Unit.

In order to approach the mechanism of Recognition Unit, it is mandatory to perform extra EEG data mining to obtain critical physiological information that is necessary to determine the mechanism. The conventional method, which is also employed in Experiment 1 and Experiment 2, provides mere information of ‘modulation’ whose significance should be solely dependent on experimental contexts. However, the mechanism of Recognition Unit is apparently independent of experimental conditions, therefore it should be asked to data themselves. For this purpose, the information-based EEG modeling approach (Onton and Makeig, 2006) was employed. This method is implemented in EEGLAB (Delorme and Makeig, 2004) and composed of independent component analysis (ICA), equivalent current dipole estimation, clustering of independent components (ICs) according to their dipole locations, event-related spectral perturbation (ERSP), and inter-trial phase coherency (ITC). With this method, we decomposed the scalp electrode EEG into clustered source-space IC activities and examined differences in their oscillatory activity represented as ERSP and ITC across three levels of familiarity. Note that although this approach is fully data-driven and free from experimental hypotheses. To maintain compatibility, conventional scalp ERP analysis was also performed to replicate previously reported N250 and P300 amplitude modulation.

For cognitive tasks, the established stimulus set in previous experiments, namely faces

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<sup>3</sup> Data in this study were published in: Miyakoshi, M., Kanayama, N., Iidaka, T., Ohira, H., 2010. EEG evidence of face-specific visual self-representation. *NeuroImage* 50, 1666-1675.

and objects of one's own, familiar, and unfamiliar, were employed. In addition to these conditions, to investigate cortical mechanism in visual self-representation, hemispheric laterality was examined by visual field manipulation. In the optic chiasm, the nerves connected to the right eye that attend to the left side of visual field (located in the right retina) remain on the right (ipsilateral) side of the brain, and the nerves from the left eye that attend to the right side of visual field (located in the left side of retina) remain on the left (ipsilateral) half of the brain. Manipulating the visual fields served as another experimental condition in an attempt to interfere with normal visual recognition (Brown and Jeeves, 1993; Brown et al., 1999). In the literature of neuropsychology (Feinberg and Keenan, 2005; Keenan et al., 2001, 2003; Sperry et al., 1979; Van Lancker, 1991), behavioral studies (Keenan et al., 1999, 2000b; Platek et al., 2004b), and fMRI studies on self-face recognition (for reviews, Northoff et al., 2006), cortical networks dedicated to self-recognition were reported to be right-lateralized. Results from Experiment 2 showed compatibility with this assumption. These findings have led to the right-hemisphere dominance hypothesis in self-recognition (for review, Keenan et al., 2000b; Van Lancker, 1991). From this hypothesis, it was predicted that self-relevant stimuli presented to the right visual hemifield would lead to anomalous visual self-recognition. The artificially introduced anomalia in visual self-recognition would help identifying the critical processes underlying the normal process.

## *4.2 Materials and Methods*

### *4.2.1 Participants*

Participants were 24 healthy graduate and undergraduate students (age: mean  $21.1 \pm 1.4$  years, range 20–26; 11 women). Written informed consent was obtained from all participants. All experimental procedures were carried out following the Declaration of Helsinki. All participants were right-handed and had normal or corrected-to-normal vision.

### *4.2.2 Stimuli*

Experimental conditions had three levels of Familiarity (self-relevant, Self; familiar, Fam; unfamiliar, Unf) and two levels of Domain (Face and Cup). The stimulus was presented either unilaterally (to the left visual field, LVF; to the right visual field, RVF) or bilaterally (identical images presented to both visual fields, BVF). The combinations of these conditions are illustrated in Figure 4.1. Before the experiment, the participant's own faces and cups were

digitally photographed. These pictures were not mirror-reversed. These photos were processed to remove the background and, for facial images, everything below the neck. These clipped-out images were converted into grayscale. Images of other levels of Familiarity were also processed in the same way. The participant’s own face served as Self-Face, and his or her own cup served as Self-Cup. A facial image of former Japanese Prime Minister Junichiro Koizumi was taken from an internet website and served as Fam-Face, while an image of a common disposable paper cup served as Fam-Cup. Images of other participants’ faces and cups served as Unf-Face and Unf-Cup, respectively. All cups brought by participants were confirmed as unique. All facial images showed neutral expressions. A post-experimental self-report confirmed that participants had not previously seen the Faces and Cups presented as Unfamiliar. The size of the fixation cross was 7 mm × 7 mm, corresponding to a visual angle of 0.45° × 0.45° at a constant viewing distance of 90 cm, provided via a fixed chin rest. The size of stimuli was 2.4 cm × 2.9 cm or 1.53° × 1.85° with an innermost edge of 21 mm or 1.34° from the center of the fixation cross.

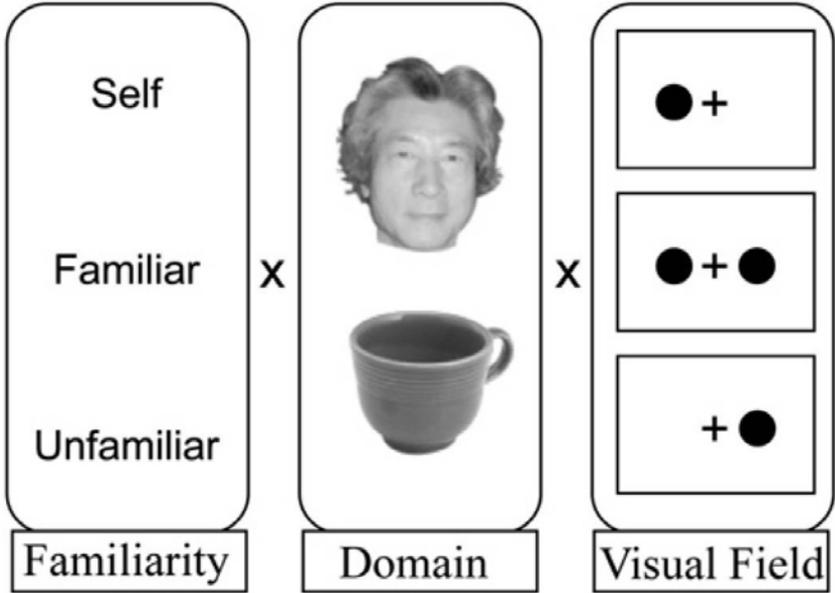


Figure 4.1 Schematic illustration of the factorial design adopted in the present experiment. There were 18 combination of conditions and 39 trials for each.

4.2.3 Experimental Procedure

Participants were comfortably seated in a dimly lit, sound-attenuated, and electrically shielded room. A chin rest was used to fix the head position. When the experiment started, a blank gray screen with the fixation cross was presented centrally for 1850 ms, and then the stimulus

was presented for 150 ms. The fixation cross was present throughout the experiment. The participants' task was to judge the level of familiarity as quickly and accurately as possible by pressing assigned keys with the index, middle, and ring fingers. Responses were made bimanually, that is with both hands, to avoid a lateral bias in the motor response (Mohr et al., 2002; Schweinberger et al., 2002b; Schweinberger et al., 2003). Key assignments were counterbalanced across participants. Each one of 18 patterns in the combination of conditions was presented 39 times. The total number of trials in the experiment was 702. An experiment was divided into three blocks, and a few minutes of rest was taken between blocks. At the beginning of the experiment, there was a two-minute practice session in which the same stimulus set was used as in the experimental sessions.

#### *4.2.4 Behavioral Data Analysis*

Mean reaction times (RTs) were tested with three-way repeated measures analysis of variance (ANOVA) with the factors Familiarity (Sel, Fam, and Unf) x Domain (Face and Cup) x Visual Field (LVF, RVF, and BVF). The Greenhouse-Geisser correction was applied wherever necessary. The significance level was set to 0.05. When the main effect or interaction reached significance, post hoc multiple comparisons were performed with Holm-Sidak correction.

#### *4.2.5 EEG Recording and Analysis*

EEG was recorded with the Nihon Koden EEG 1100 (Tokyo, Japan) 33-channel EEG recording unit. EEG signals were recorded with a 120-Hz low-pass filter (12 dB/oct). The sampling rate was 500 Hz and was later downsampled to 200 Hz. The resolution of A/D conversion was 16 bit. Ag/AgCl electrodes were placed on 33 scalp sites: AFp9 as left electrooculogram (EOG), Fp1, Fp2, Fz, F3, F4, F7, F8, FC1, FC2, FC5, FC6, Cz, C3, C4, T7, T8, CP1, CP2, CP5, CP6, TP9, TP10, Pz, P3, P4, P7, P8, O1, O2, PO9, PO10, and Iz, according to the international 10-10 system. All electrode impedance was kept below 10 k $\Omega$  and typically below 5 k $\Omega$ . EEG electrodes were initially referenced to a nose tip, and later an average reference was calculated.

EEG data analysis was performed using EEGLAB 6.01b (Delorme and Makeig, 2004; <http://www.scn.ucsd.edu/eeglab>) running under Matlab 7.5 (MathWorks, Natick, MA, USA). A high-pass FIR filter of 1 Hz (transient bandwidth 0.2 Hz) was applied to continuous EEG data to remove a linear trend to stabilize the results of subsequent ICA. EEG data were

segmented into epochs starting 400 ms prior to and ending 1000 ms after the stimulus onset. For averaged ERP analyses, the baseline activity was calculated between -200 ms to 0 ms relative to stimulus onset. EEG data of correctly responded trials were included in the dataset. All epochs were visually inspected to discard trials with irregular noise. Typical physiological artifacts such as eye blinks, eye movement, or muscle potentials were kept for the next ICA process. The extended Infomax ICA with natural gradient (implemented in EEGLAB) was performed to obtain 33 ICs from each of 24 datasets. Upon IC activation, joint probability and kurtosis were calculated to find epochs with improbable activity (implemented in EEGLAB; for detail, Delorme et al., 2007a). The rejection threshold was set to 5 SD and 8 SD, respectively. Visual inspection was performed on the data, and a second ICA was run on pruned data. The same rejection procedure was run again. As a result, 12.8% (SD = 3.0) of epochs was rejected, and a mean of 31.5 epochs (SD = 3.4, range 20–39) remained per condition. The ICA was performed again to obtain the final decomposition. For each IC, an equivalent current dipole was estimated using DIPFIT 2.2 (EEGLAB plug-in using Fieldtrip toolbox functions by Robert Oostenveld) using the head model with the Montreal Neurological Institute (MNI) standard coordinate system. Out of 792 (24 datasets  $\times$  33 ICs) dipoles, 82 (10.4%) were rejected because of residual variance  $>$  30%. The mean residual variance of the remaining 710 dipoles was 10.0% (SD = 7.7). Scalp topography, averaged ERP, averaged ERSP, EEG spectra, and averaged ITC were calculated for each IC. For ERSP and ITC calculation, the Morlet wavelet was used. Log-spaced 63 frequencies ranging from 3 Hz to 50 Hz were calculated every 5 ms starting from 400 ms prior to and ending up to 1000 ms following stimulus onset (baseline from -400 ms to -200 ms) with a linearly increasing wavelet cycle of 1 at 3 Hz and 7 at 50 Hz. The maximum wavelet window length was 375 ms at 3 Hz. Data dimensions of ERSP and ITC were reduced to 10 with PCA, and IC clustering was performed using k-means with the criteria of dipole locations (normalization weight, 5), ITC (latency, 0–900 ms; frequency, 3–20 Hz; normalization weight, 3), and ERSP (latency, 0–900 ms; frequency, 3–20 Hz; normalization weight, 1) to generate 10 IC clusters. Out of 710 ICs, 92 (13.0%) did not fall within 2 SD from any cluster and were excluded as outliers. The IC clusters were visually inspected to determine their physiological significance. As a result, oscillatory dynamics of interest were found in two IC clusters; detailed profiles are addressed in the following section. Two of ten IC clusters may appear insufficient to represent whole EEG activity. However, in the process of decomposition, each IC was calculated from all scalp channel activities, i.e. any single IC comprises all scalp channel information for each time point. This virtue of ICA is also valid for non-time-series data decomposition (e.g., used for the MR image filter, Miyakoshi et al., 2009; Nakai et al., 2004). ICA is now widely used

in various fields and the consensus of reliability is established. Focusing these IC clusters is an effective way to exploit information, compared with focusing on a representative single scalp electrode or the mean of several electrodes.

When performing statistical tests on ERSP and ITC, nonparametric bootstrapping and permutation with pseudo  $F$ -tests for comparing levels of Familiarity and pseudo  $t$ -tests for comparing Self-Face LVF versus Self-Face RVF were performed (Nichols and Holmes, 2001; Trujillo and Allen, 2007). The moving average for pseudo  $F$ - and  $t$ -tests was approximately 5%. First, uncorrected  $p$ -values were calculated for every pixel in the following way. Under the null hypotheses, the distribution of  $F$ - and  $t$ -statistics was computed from 10,000 random permutations across ICs at each time point. The one-tailed cutoff value was set to 0.01, which determines  $10,000 * 0.01 = 100$ th value from the end of the distribution. Observed time-frequency responses exceeding the limits thus indicate statistical differences with uncorrected  $P$ -values. Then, the correction for multiple comparisons was performed with a single-step nonparametric multiple comparisons permutation test. This test is known to have strong control over Type-1 error (for proof, Holmes et al., 1996). Maxima of every time-frequency map of the surrogate data were extracted to construct the distribution of maxima. The one-tailed cutoff value was determined by  $10,000 * 0.01 = 100$ th value from the right end. All time-frequency points with observed  $F$ - and  $t$ -statistics greater than this cutoff value represent corrected statistical significance. Other pixels below the cut-off values were masked.

Conventional averaged ERPs of scalp channels were also calculated at Pz, P7, and P8. In this calculation, ICs classified to EOG clusters were rejected from datasets, and the remaining ICs were backprojected to recompose scalp EEG without EOG. The same ANOVA and multiple comparison design used in the behavioral data analysis were applied to each channel's data. For testing the effect of Visual Field on N170, individual N170 peak amplitude and latency at P7 and P8 were calculated, and the means of the 2 channels were tested with the same ANOVA design as above. N250 was tested with a mean ERP of 200 ms to 300 ms poststimulus at P8, and P300 was tested with a mean ERP of 300 ms to 550 ms poststimulus at Pz.

## 4.3 Results

### 4.3.1 Behavioral Data

Participants' hit rates were generally high ( $M = 92.4\%$ ,  $SD = 2.7$ ). Repeated measures

ANOVAs on RTs revealed an interaction of Domain versus Familiarity,  $F(2, 46) = 3.68, P < 0.05$ . Subsequent multiple comparisons revealed significantly shorter RTs for Sel-Face ( $M = 544.1, SD = 46.2$ ) than for Fam-Face and Unf-Face ( $M = 581.6, SD = 43.6$  and  $M = 588.2, SD = 60.4$ , respectively) and shorter RTs for Sel-Cup ( $M = 569.5, SD = 44.7$ ) than for Unf-Cup ( $M = 602.9, SD = 69.6$ ) (all  $P < 0.05$ ) (Figure 4.2, center). The test also revealed significant differences between Self-Face and Self-Cup ( $P < 0.001$ ). These results suggest general RT enhancement for Self, but especially for Self-Face compared with Self-Cup.

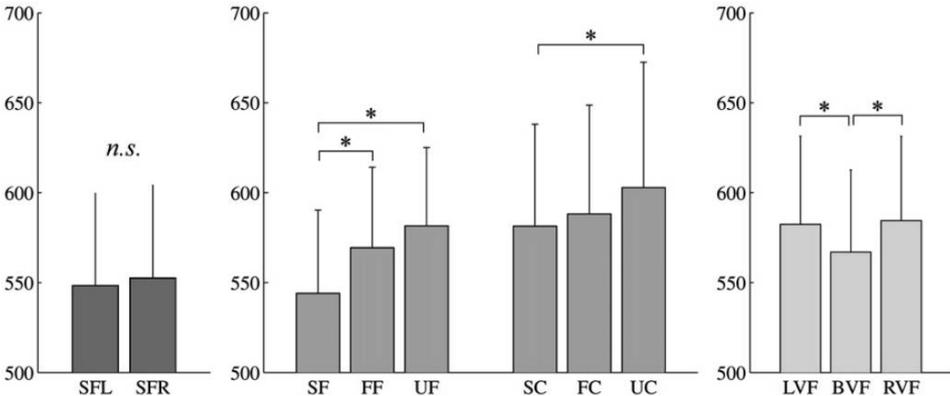


Figure 4.2 Left, Mean reaction times (RTs) for the interaction Familiarity versus Visual Field. The error bars show 1SD. SFL, Self-Face in the Left visual field; SFR, Self-Face in the Right visual field. Center, The interaction of Familiarity versus Domain. SF, Self-Face; FF, Familiar-Face; UF, Unfamiliar-Face; SC, Self-Cup; FC, Familiar-Cup; UC, Unfamiliar-Cup. Right, The main effect Visual Field. LVF, left visual field; BVF, bilateral visual fields; RVF, right visual field. \*  $P < 0.05$ .

4.3.2 EEG Results

4.3.2.1 Grand mean ERP for Face and Cup

Figure 4.3 shows grand mean ERPs for Face from all scalp EEG channels, and Figure 4.4 shows that for Cup. Particular ERP components of interest are focused on in other figures.

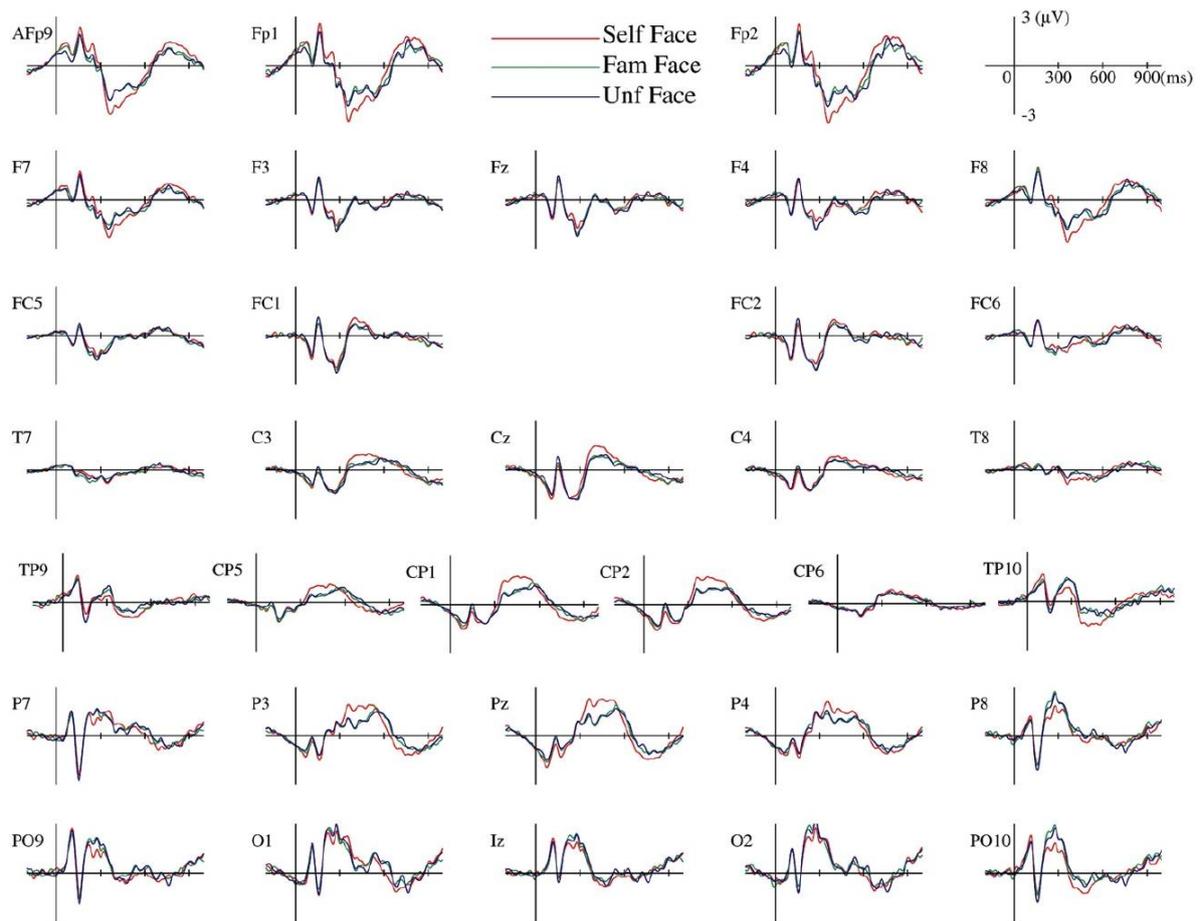


Figure 4.3 Grand mean ERPs for Face. Note the condition Visual Field is collapsed.

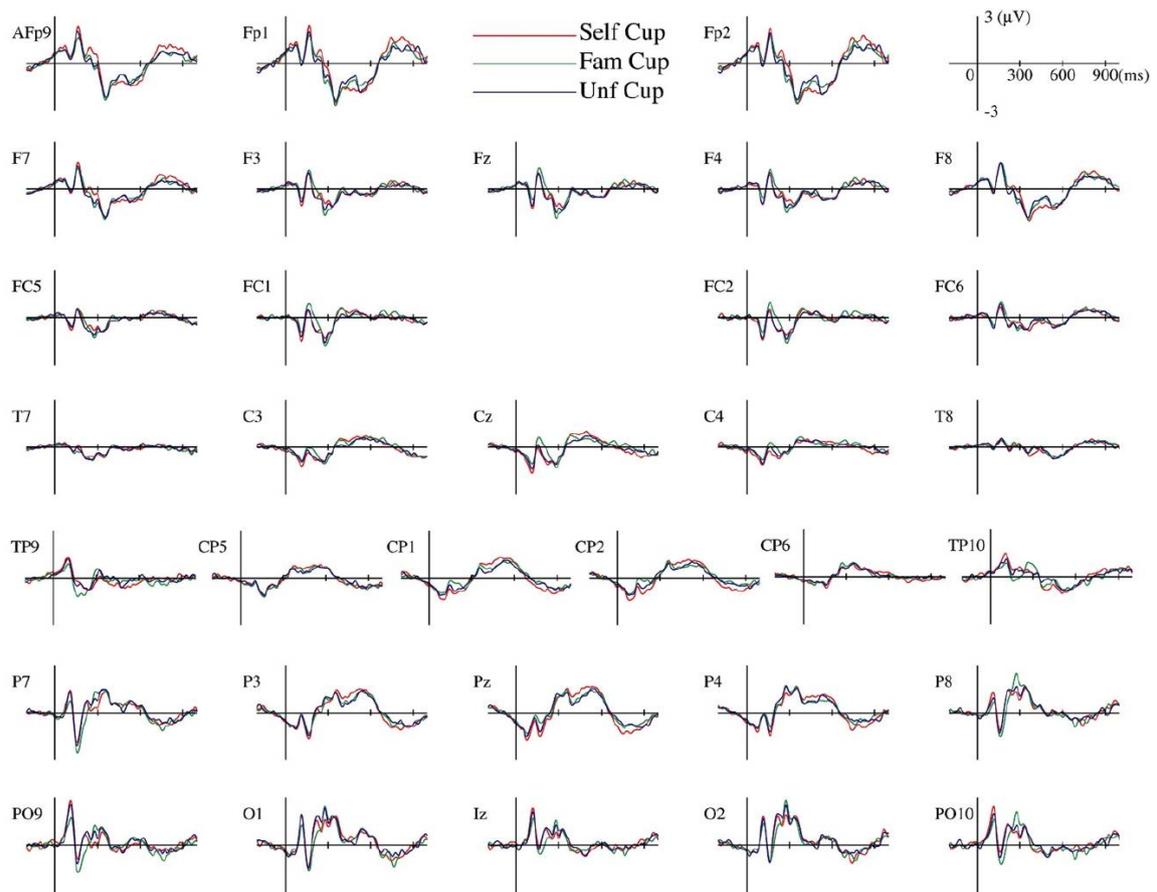


Figure 4.4 Grand mean ERPs for Cup. Note the condition Visual Field is collapsed.

#### 4.3.2.2 N250 and underlying EEG dynamics

Information-based EEG modeling found an IC cluster whose properties indicate probable source of N250. To this cluster, 50 ICs from 22 participants contributed. The Montreal Neurological Institute (MNI) coordinates for the centroid of the dipoles was (49, -69, -10), which falls within the right fusiform gyrus. The mean residual variance was 9.93% (Figure 4.5). This IC cluster is henceforth referred to as rFG according to its dipole centroid. The early ITC modulation started from the high alpha range (up to 12 Hz) and gradually came down to the theta range (down to 4 Hz), which occurred within 170–290 ms poststimulus (Figure 4.6a, 4.6b). Importantly, it confirmed a clear ITC decrease for Self-Face (Figure 4.6c, 4.6d). Critically, the latency of the ITC modulation overlaps N250, therefore N250 at P8 was calculated. Repeated measures ANOVAs only revealed, except for Visual Field, the main effect Familiarity,  $F(2,46) = 11.46$ ,  $P < 0.001$ , under which differences between Self and Fam as well as between Self and Unf were significant (all  $P < 0.01$ ) (Figure 4.7). Corresponding ERSP did not survive statistical tests. Thus the results suggest dominance of ITC on N250 modulation.

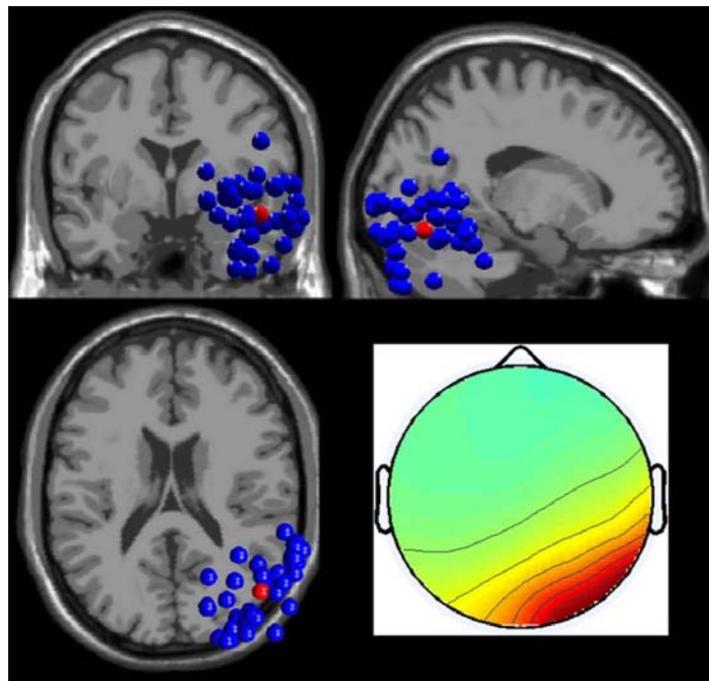


Figure 4.5 Estimated current dipoles from each participating independent component (IC; blue) and their centroid (red) from the cluster right fusiform gyrus (rFG). The rendered maps are coronal (top left), sagittal (top right), and axial (bottom left) slices of the MNI template. Their averaged scalp topography is shown in the bottom right.

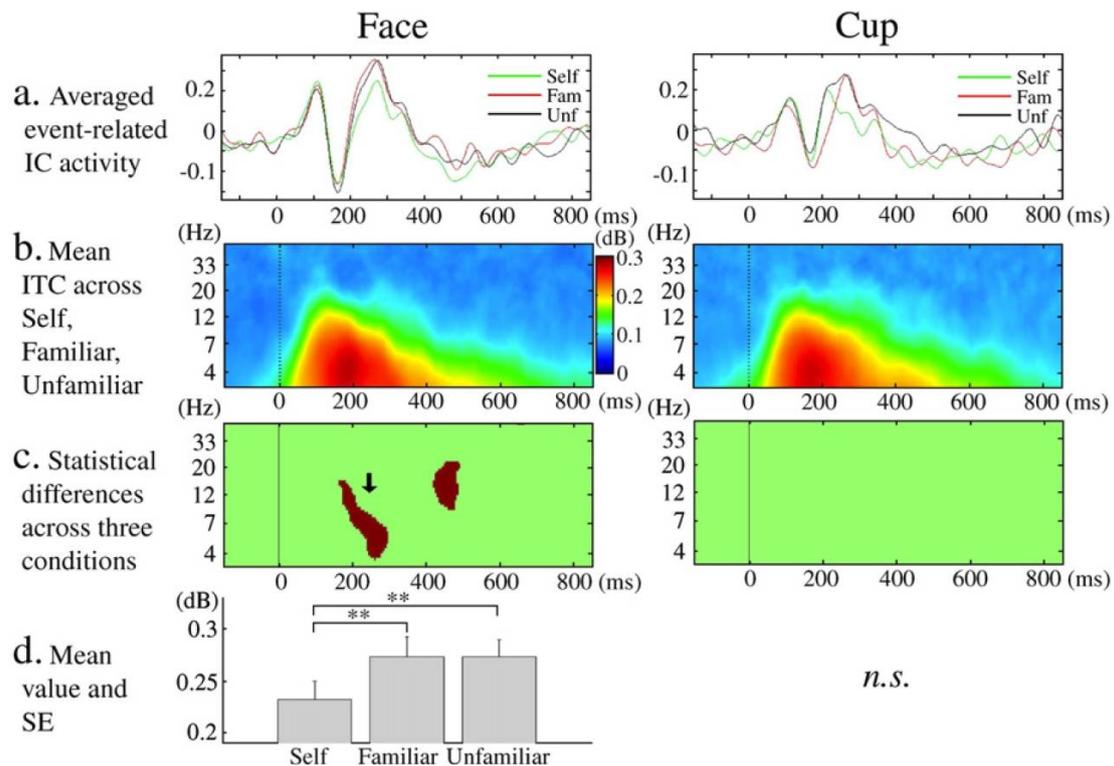


Figure 4.6 Independent component (IC) activities in the cluster rFG (see Figure 4.5). The left column shows data for Face, while the right column shows data for Cup. a, averaged event-related IC activity; b, the time-frequency plot of inter-trial phase coherence (ITC); c, ITC plot of pixels that showed statistical differences across levels of Familiarity ( $P < 0.01$ , corrected); d, the mean values with 1SE of the highlighted pixels indicated by arrows. \*  $p < 0.05$ ; \*\*  $p < 0.005$ . ERSP plot is omitted because there was no pixel that showed significant difference across levels of familiarity.

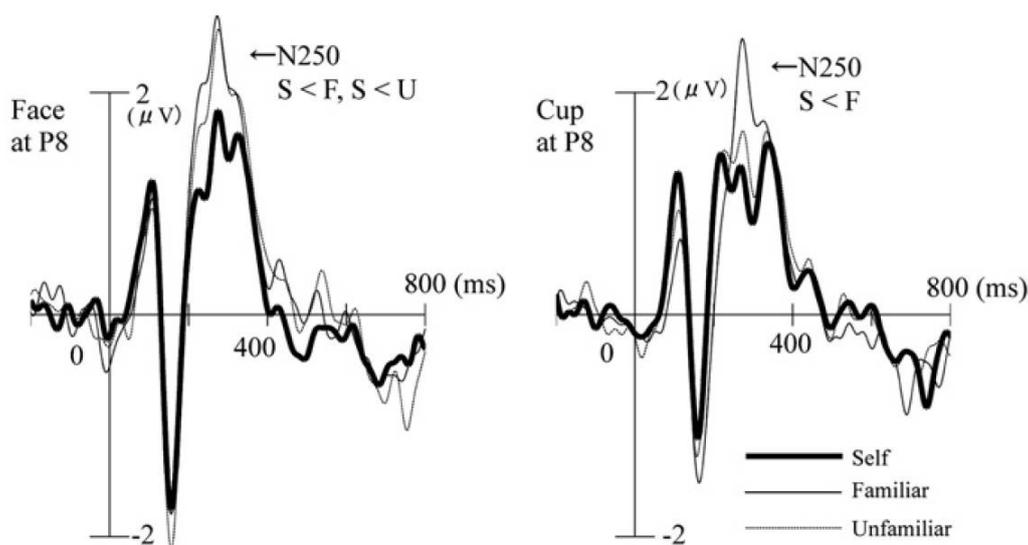


Figure 4.7 Averaged event-related brain potentials (ERPs) from P8 showing the main effect of Familiarity.

#### 4.3.2.3 ERSP and ITC modulation in medial frontal area

Similarly, information-based EEG modeling found another IC cluster that showed modulation for Self. To this cluster, 50 ICs from 22 participants contributed. The MNI coordinates for the centroid of the dipole cluster was (0, 13, -19), which falls within the medial prefrontal cortex, and the mean residual variance was 8.57% (Figure 4.8). Hence, this IC cluster will be referred to as mPFC according to the location of the centroid. Statistical tests across levels of Familiarity revealed ITC modulation in the theta range between 270–390 ms poststimulus (Figure 4.9e). Detailed latency comparison revealed that the modulation for Self-Face is approximately 70 ms earlier than that for Self-Cup (270–320 ms versus 340–390 ms). Importantly, the pattern of distinction across levels of Familiarity was not identical between Face and Cup (Figure 4.9f, 4.9g). The results suggest self-specific ITC modulation for Face but not for Cups.

ERSP modulation was also observed (Figure 4.9b). It was only for Self-Face (Figure 4.9c, 4.9d). The latency of the self-face-specific ERSP modulation overlaps that of peak amplitude modulation (390 ms poststimulus) in averaged IC activation (Figure 4.9a), which is reminiscent of previously reported self-face-specific P300. For confirmation, P300 was calculated at Pz and tested with ANOVAs. A significant interaction for Familiarity versus Domain was found,  $F(2, 46) = 6.58$ ,  $P < 0.005$  (Figure 4.9i). The results suggest that the ERSP modulation may underlie EEG dynamics that construct self-face-specific P300.

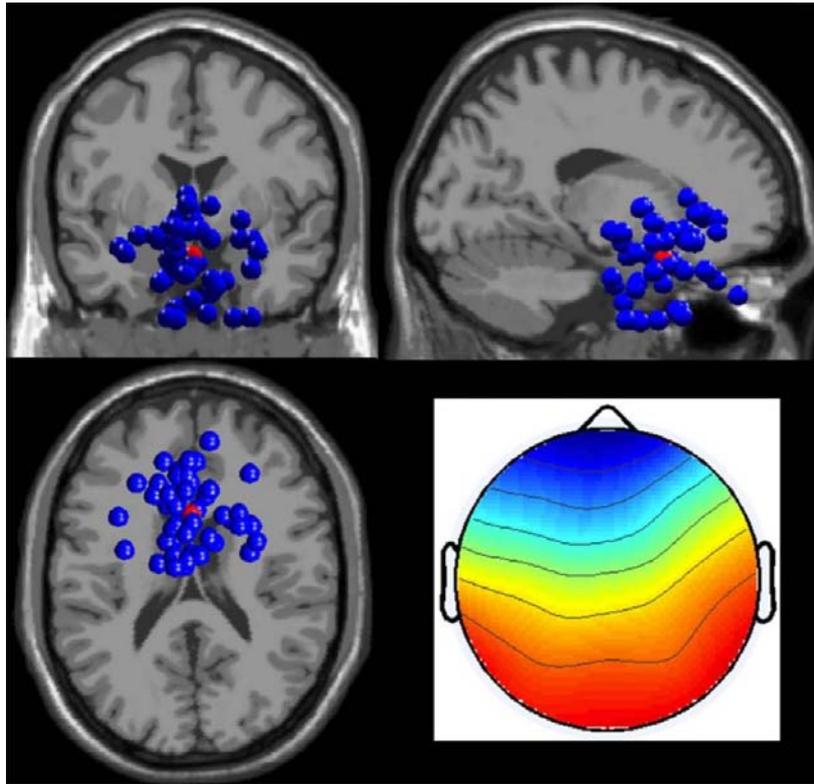


Figure 4.8 Estimated current dipoles from each participating independent component (IC; blue) and their centroid (red) from the cluster mPFC. The rendered maps are coronal (top left), sagittal (top right), and axial (bottom left) slices of the Montreal Neurological Institute (MNI) template. Their averaged scalp topography is shown in the bottom right.

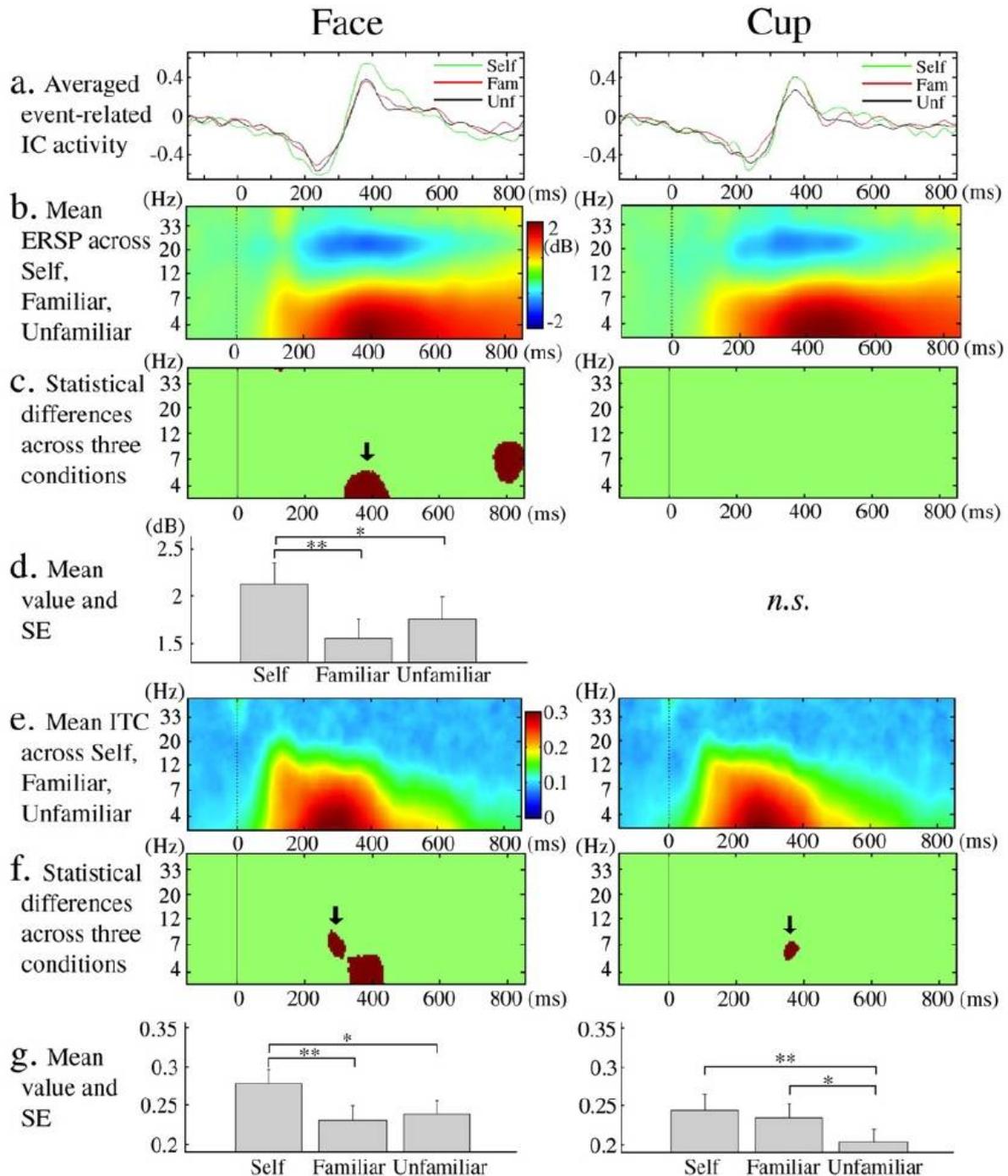


Figure 4.9 Independent component (IC) activities in medial prefrontal cortex (mPFC) cluster (see Figure 4.8). a, averaged event-related IC activity; b, the time-frequency plot of event-related spectral perturbation (ERSP); c, ERSP plot of pixels that showed statistical differences across levels of Familiarity ( $p < 0.01$ , corrected); d, the mean values and 1SE of the highlighted pixels; e, ITC plot; f, ITC of statistical difference across levels of Familiarity ( $p < 0.01$ , corrected); g, the mean values and 1SE of the highlighted pixels. \*  $p < 0.05$ ; \*\*  $p < 0.005$ .

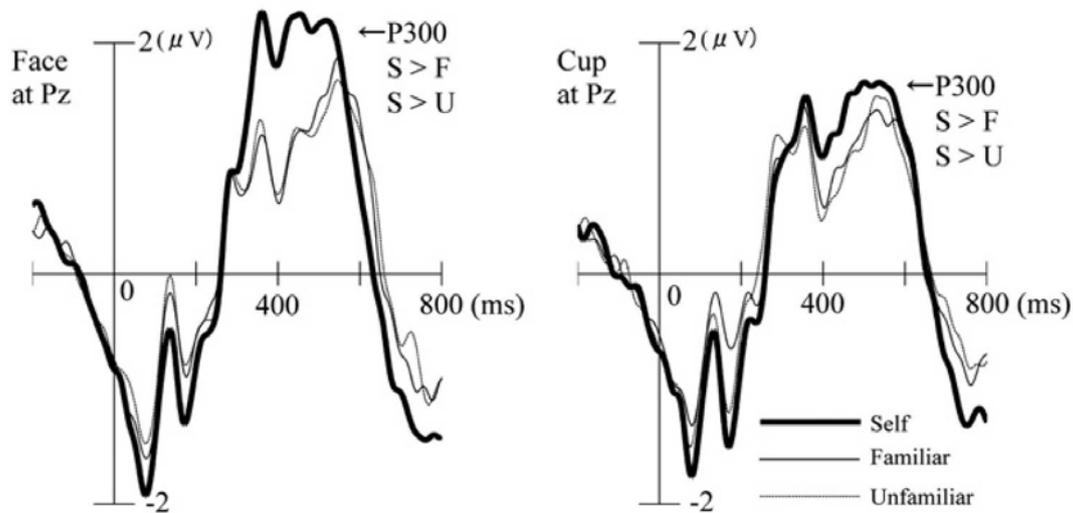


Figure 4.91 Averaged event-related brain potentials (ERPs) from Pz showing the interaction Familiarity vs Domain.

#### 4.4 Discussion

The critical question in the Experiment 3 was how the functionality of Recognition Unit is represented and mediated by the neural mechanism. The information-based EEG modeling approach found the IC cluster that accounts for N250. Detailed examination of event-related oscillatory properties revealed ITC decrease for self-face. On the other hand, there was another IC cluster that explains P300. Details are discussed below.

##### 4.4.1 Making inference of the mechanism underlying Recognition Unit

N250 reflected face-specific self-representation. N250 is the earliest ERP component reflecting self–other distinction (Miyakoshi et al., 2008; Tanaka et al., 2006), but the physiological significance of this component remains unclear. The results from the present study not only replicated earlier findings but also clarified that the decrease of the ITC in the continuous alpha-theta complex range explains the N250 modulation. The phenomenon of ITC has been reported in several studies, often with other nomenclature (e.g., Gruber et al., 2004; Rodriguez et al., 1999; Schack and Klimesch, 2002; Tallon-Baudry et al., 1996). ITC represents stimulus-induced resetting of the phase of ongoing field potential oscillations, and an increase in ITC means that uniform phase distribution is weighted toward a dominant phase (Makeig et al., 2002). The functional meaning of an ITC increase is the reflection of the exact timing of the sequential temporal activities of neural processes in response to incoming

sensory stimuli (Sauseng and Klimesch, 2008). Klimesch et al. (2007) proposed that, when bottom-up sensory processing interacts with top-down processes, a highly selective and excitatory encoding network emerges, which an ITC increase may reflect as an early inhibitory filter enabling such interaction. ITC modulation, or phase-resetting, suggests a temporally regulated sequence of neuronal activation. It is intriguing that the initial detection of self-face in Recognition Unit is associated with *decrease* of phase-resetting. This may be rather an unexpected, or even counter-intuitive results, if one is familiar with P300 studies on self-recognition paradigms in which Self has always been associated with *increase* of P300. The increase of P300 is explained by increase of ERSP (e.g. pure EEG amplitude) and ITC, as was observed also in the present study. It is also notable that ERSP modulation did not contribute to N250 modulation, suggesting dominance of phase-resetting in N250 modulation.

The findings from this experiment provide important clues in making inference of underlying mechanism of Recognition Unit. There are largely two types in neuronal network systems: population coding and sparse coding. The results of phase-resetting *decrease* rejects the possibility of involvement of population coding and supports the possibility of sparse coding. This is in a good agreement with N250r literature that is the most established ERP index of the priming effect (Schweinberger et al., 1995, 2002, 2004; Pickering et al., 2002; Pfützte et al., 2002; Begleiter et al., 1995). The basic idea of the sparse coding is expressed as the ‘sharpening process’ that was addressed in the context of priming effect (Desimone, 1996; Grill-Spector, 2006; Wiggs and Martin, 1998). According to these authors, familiarization is mediated by sharpening the corresponding cellular networks to be sparser so that the networks respond rapidly and effectively. The result of phase-resetting decrease suggests correspondence to the activation of specially sharpened network. The schematic illustration of this relation is shown in Figure 4.92. Note that the authors referred to the relation between the sharpened networks and behavioral enhancement, which was maximal for Self-Face in the present study. The decrease of phase-resetting for Self-Face may therefore be a manifest of engaging specially sharpened neuronal networks in self-face recognition.

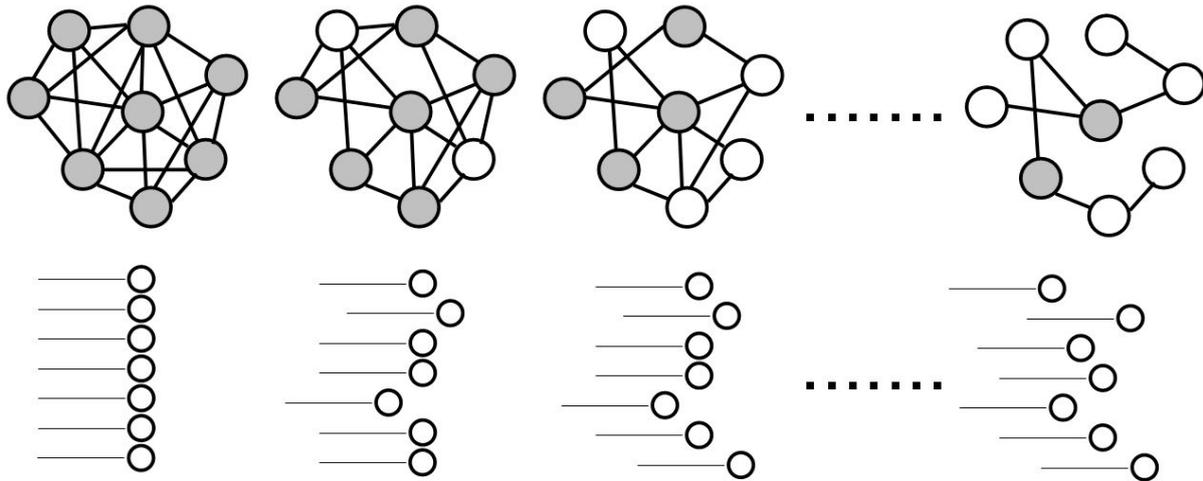


Figure 4.92 The illustration for sparse network through the sharpening process, and resultant phase-resetting decrease. In the figure, activation of highly sparse network is reflected by less temporally coordinated (i.e. less-synchronized) neuronal firing. Note that these neurons, especially those that are located in the ventral stream, are always firing spontaneously and randomly, which composes ‘background EEG’.

#### 4.4.2 Revisiting domain-dependency of visual self-recognition

The results from the present study revealed comparable ITC modulation for both Face and Cup in the same IC cluster mPFC. Considering that ITC modulation was found in the medial frontal area and with relatively late latency (most likely contributing to P300), it seems reasonable to assume that the oscillatory modulation is related to familiarity processes in rather higher cognitive stages. The results support the possibility of involving the population coding for the responsible local neural ensemble, which is in clear contrast with the case of N250 and underlying oscillation. The results showed, however, the different responses to each stimulus domain; a Self-specific ITC increase was observed for Face but not for Cup. Moreover, it was accompanied by an ERSP increase for Self-Face but not for Self-Cup. It indicates that visual representation of one’s own face does not necessarily have oscillatory states in common with that of one’s own personal properties. These findings seem to support the view that visual self-representation is domain-specific. The results are in harmony with the Experiment 1 as well as Sugiura et al. (2008).

The mPFC cluster showed face-specific visual self-representation, but Sugiura et al. (2008) concluded that medial cortical structures are not relevant to self-other distinction. They found the main effect of familiarity in this area, which showed a specific decrease for the Unfamiliar category and domain-generally (i.e., both for Face and Name). Activation in the

same area modulated by facial familiarity was also reported by Eger et al. (2005). Our interpretation of this discrepancy is that at least a part of the medial frontal area is involved not only in familiarity distinction but also face-specific self-representation. However, this may be only observed as transient neuronal activation that BOLD signal changes cannot resolve in the temporal domain. Furthermore, the ITC modulation observed in the present study is not related, at least theoretically, to neuronal energy consumption since ITC is a measure of temporal regulation of oscillation which is independent of amplitude measurement i.e. ERSP. The differences in what are reflected by ITC and BOLD signal changes may explain another reason for the discrepancy between the present study and previous fMRI studies. It should be noted, however, that information-based EEG modeling is a fully data-driven approach, and the spatial information represented by dipoles is only one of the constraints to forming clusters. The discrepancy in results from two studies could be explained by the difference in the roles of spatial information. It may be of interest for future fMRI studies to examine if there is mPFC activation that highly varies across individuals.

In conventional ERP analysis, results from the present study replicated the self–other distinction in face recognition measured with P300 (Miyakoshi et al., 2008; Ninomiya et al., 1998; Tanaka et al., 2006). The time-frequency decomposition on the cluster mPFC revealed that the increase of theta ERSP is likely to contribute to the self-face-specific P300. Functional significance of mPFC theta modulation has been investigated in simultaneous fMRI-EEG recording studies in which higher-order cognitive tasks such as mental arithmetic increased theta power (Mizuhara et al., 2004; Sammer et al., 2007). Sammer et al. (2007) concluded that frontal theta oscillation is a marker of comprehensive functional brain states rather than specific processes in the brain. This notion is in line with the fact that P300 has a broad range of sensitivity to cognitive processes in general (Johnson, 1986; Kok, 2001). Enhanced P300 to one’s own face may thus indicate engaging such comprehensive cognitive function in processing visually evoked self-representation.

Another example of the functional role of the theta ERSP was reported by Delorme et al. (2007b). They found a correlation between mPFC theta ERSP and RTs during a visual attention task and interpreted mPFC theta ERSP as a manifestation of limbic processes involved in disinhibiting impulsive motor responses to rewarding or goal-fulfilling events. In the present study, larger mPFC theta ERSP was associated with faster RTs and larger P300 amplitude. Importantly, the time course of theta ITC modulation for face was 270–320 ms poststimulus that precedes mPFC theta ERSP modulation, P300, and RTs. This may indicate that the observed ITC modulation is the earliest frontal activity sensitive to face-specific self-representation, possibly coordinating subsequent cognitive and motor processes to enable

enhanced performance for one's own face.

It would be informative to know the encounter frequencies for each category of objects (except for Unf), if such were available, when interpreting the results from the present study. However, the shortest RT for Self-Face should be explained by the highest degree of familiarity, which can be caused by the highest encounter frequency or some other form such as the highest richness in semantic representation. The idea that semantic familiarity is represented in the ventral visual pathway is a view supported by evidence confirmed in the Experiment 2. In addition, Schweinberger et al. (2004) also showed that not only perceptual fluency, but also semantic familiarity is reflected by N250r, which is the term specifically applied when N250 is measured in the immediate priming paradigm. When considering visual familiarity to one's own face, semantic familiarity, in addition to encounter frequency, may also have a role.

#### *4.4.3 Conclusion*

Results from the present study supported the view that the initial detection of visual self-relevance is mediated by sparse coded network activation. This is the probable mechanism of Recognition Unit supported by oscillatory evidence that showed phase-reset *decrease* for self-face recognition in fusiform areas. The decreased phase-resetting was interpreted as less temporally coordinated activity in a local neural network, which most likely reflects less cognitive demand. The result was in contrast with ERSP and ITC increase in the medial frontal areas, which suggests involvement of population coding in visual self-recognition in the later time-course. This activity also showed domain-dependent responsiveness and replicated the conclusion of Experiment 1. Taken together, there are at least two major stages in visual self-recognition; initially mediated by sparse-coded network in the ventral stream, and later mediated by population-coded network in the medial prefrontal cortex. Hemispheric difference in visual self-representation remains unclear.

## Chapter 5

### *Conclusions*

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#### *5.1 Summary of empirical findings in the present study*

In Chapter 2, N250 response to self-relevant objects was examined to elucidate domain-generalty of Recognition Unit. The motive of this experiment was to confirm whether there is ever preferred domains by Recognition Unit in processing visual self-relevance recognition. Presented stimuli were tools of daily use which were divided into three experimental categories of familiarity including self-relevant, familiar, and unfamiliar. N250 elicited to each level of familiarity was measured. Results confirmed that N250 was elicited to both visual self-relevance and mere familiarity with no significant difference, whereas it was not elicited for unfamiliar objects. This is in contrast to literature of self-face recognition studies (Caharel et al., 2002; Tanaka et al., 2006) in which N250 dissociated visual self-relevance to faces from mere familiarity to faces. Together, the results from this experiment suggests that visual self-relevance is not domain-general but domain-dependent. Because Recognition Unit is the first visual processing module among others, domains preferred by Recognition Unit, typically faces, receive preferential processes of visual self-relevance recognition. In other words, visual self-relevance with faces is detected 200-300ms after presentation, but that with objects is detected only after 300ms, because the former is readily detected by Recognition Unit but the latter is not.

In Chapter 3, represented familiarity by Recognition Unit was tested by asking whether it is perceptual or semantic. This was done by measuring N250 response to one's own profile, which is semantically familiar but perceptually non-fluent. The experimental design contains the condition Viewpoint (frontal and profile) and Familiarity (Self, Famous, and Unfamiliar). Results confirmed the effect of viewpoint variance on N250 only for unfamiliar faces. For Self and Famous, N250 difference between facial angles was diminished. The results support the conclusion that Recognition Unit processes abstract representation of visual self-relevance whose nature is beyond-perceptual.

In Chapter 4, the mechanism underlying Recognition Unit was investigated. Information-based EEG modeling was adopted to obtain indices that can legitimately determine the types of neural mechanism underlying N250. In addition, hemispheric differences in the relevant visual process was examined. The experimental design comprised of Familiarity (Self, Famous, and Unfamiliar), Domain (Face and Cup), and Visual Field (Left, Right, Bilateral). Results found phase-reset *decrease* for self-face recognition during latency

of N250 and near right the fusiform gyrus. The results supported the view that sparse-coded networks are involved when processing self-face. The hemispheric difference was not clear. N250 can be interpreted as reflection of sparse-coded network activation, which suggests past sharpening process via repetitive encounters. On the other hand, in the later time-course self-face is associated with ERS and ITC *increase* in medial prefrontal area, which indicate activation in a population-coded neural network. Taken together, EEG evidence suggests that the mechanism underlying Recognition Unit is sparse-coding. In other words, the neural representation of visual self-relevance in the ventral stream is sparse-coded local neuron ensemble.

Through above investigations, the two key questions asked in the introduction of this thesis, namely the *when question* and the *how question*, were clarified. To sum, the initial detection of self-relevance occurs between 200 ms and 300 ms after stimulus onset. This process is domain-dependent, and engages sparse-coded neural networks. The schematic illustration of the summary of empirical findings is shown in Figure 5.1.

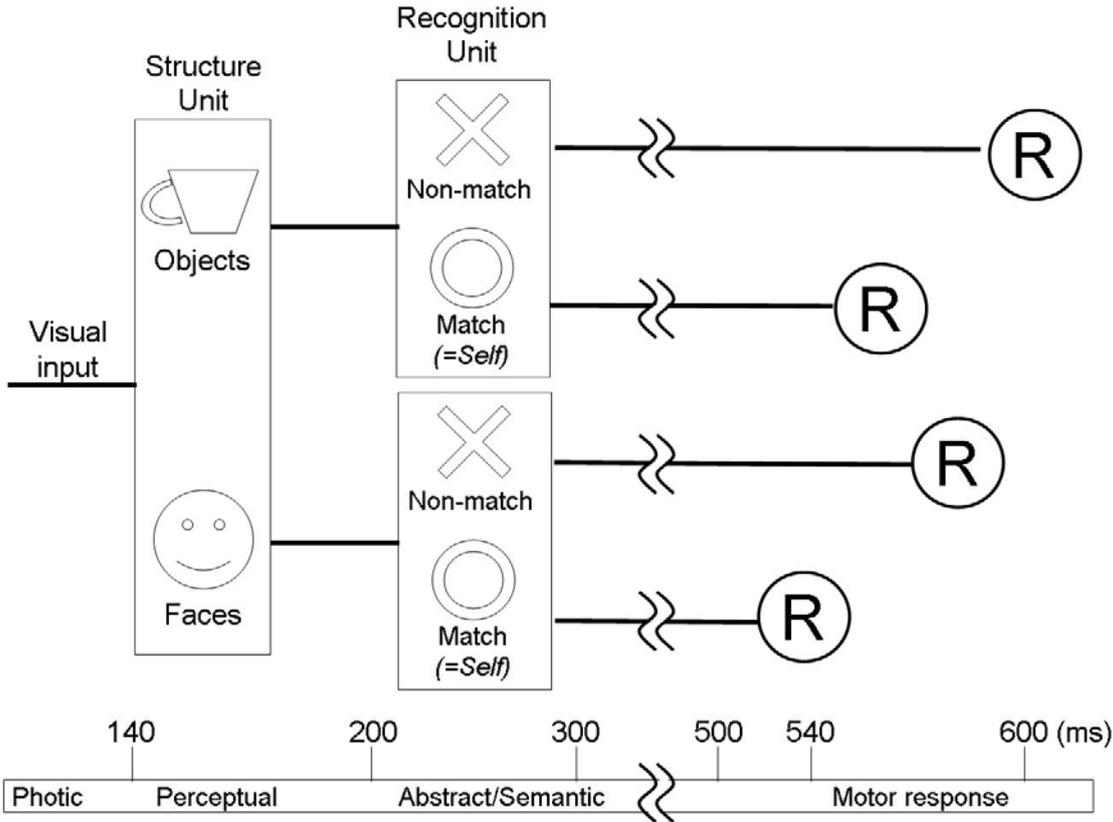


Figure 5.1 Schematic illustration explaining the results from the three experiments conducted in the present research. The time scale in the bottom shows the latency after visual stimulus onset. In the figure, R represents for the timing of responses made by participant.

## *5.2 Primary contributions of this study*

Findings in the first experiment clarified that the initial visual representation of self-relevance is domain-dependent, and Recognition Unit has a preference in visual self-relevance recognition (faces more preferred than tools of daily use). It means that self-relevance with faces would be detected fast (within 200-300ms) because Recognition Unit responds to it, while self-relevance with objects would be detected only slowly (never before 300ms) because Recognition Unit is not sensitive to them.

Domain-dependency in visual self-relevance recognition clarified in this experiment is, together with Sugiura et al. (2008), in contrast with the conventional view that the concept of the 'Self' is domain-general (e.g. Van Lancker, 1991; Keenan et al., 2000b; Decety and Sommerville, 2003; Feinberg and Keenan, 2005). The finding is all the more important because the result was confirmed by N250. In fMRI study, Sugiura et al. (2005b) similarly performed a visual self-relevance recognition task by presenting participants' own objects, but the results were rather unexpected and the obtained activation map was hardly interpretable. The bottom line is that they failed to find any relevance to results from self-face recognition. In contrast, the present experiment showed N250 modulation for familiar and self-relevant objects, which is consistent with results from previous face recognition studies. The present result suggests involvement of the same module in familiarity recognition for both faces and objects.

The results in the second experiment are important as the first demonstration showing that rather abstract representation of visual self-relevance, which is beyond-perceptual, is processed in Recognition Unit. This conclusion is inconsistent with that of Troje and Kersten (1999), who concluded that visual self-recognition is mediated by perceptual fluency. However, the discrepancy can be readily accountable. ERP components are sensitive to the priming effect (e.g., Schweinberger et al., 1995). In the present experiment, stimuli were repeatedly presented (50 repetitions for each stimulus) because it is difficult to prepare a large number of variations of one's own face. This introduced over-learning to stimuli during the experiment, which eliminated the initial lack of perceptual fluency. The results from two experiments therefore are not contradictory, but rather show different phases of the same cognitive events. The initial and singular trial of self-face recognition follows the explanation of Troje and Kersten (1999), while during experiencing repetitive recognition it follows the results from Experiment 2. This can be clearly seen the results from Tong and Nakayama (1999). They presented an illustrative plot of exponentially decreasing reaction times as the number of trials increase. In their plot, data points near the starting point explains the result in

Troje and Kersten (1999), while that after exponential decrease shows the result from Experiment 2. This integrated view suggests highly non-linear behavioral and psychophysiological sensitivity due to repetition suppression (Desimone, 1996; Wiggs and Martin, 1998).

Results from the Experiment 3 provide evidence that interconnect the Bruce and Young model (Recognition Unit), ERP study (N250), and possible neural mechanism (Sparse-coded network). Before this experiment, few attempts have been made to explain N250 modulation in the light of the neural mechanism. Furthermore, results suggests that ERSP and ITC increase underlie P300, suggesting the mechanisms of population-coding. The results thus showed two distinct stages in visual self-recognition that are based on different time-course, cortical location, and neural mechanisms.

### *5.3 Hypothetical model and physiological validity*

It is now possible to integrate the empirical findings from the three experiments presented above to construct an integrative model. The schematic illustration of this model is shown in Figure 5.2. This model explains the initial detection of visual self-relevance, and transmission of detected information to the subsequent process modules. It should be emphasized that the proposed model is founded upon empirical evidence obtained from EEG studies, therefore each module and process is given with latency information in millisecond from perceptual onset, which helps to illustrate the chronoarchitecture of the entire flow of the cognitive and neural processes in the ventral visual pathway. There has been no comprehensive (i.e. including the motor response output stage) chronoarchitectural model of visual self-relevance recognition like this, therefore this proposal would certainly make a progress in the research field of visual self-relevance recognition.

In this model, the first two modules for Photic perception and Structural Coding are not relevant to visual self-recognition. The critical process takes place in Recognition Unit where visual self-relevance is detected. Note this process is domain-dependent, and the earliest self-relevance detection is most probably applied to face stimuli, which explains the shortest RT. The detection of self-relevance in Recognition Unit, latency of 200ms-300ms poststimulus, subsequently modulates at least two cognitive and executive functions. One is potential memory processes, while the other is the motor output, both of which modulates P300 and underlying EEG oscillation represented by ITC and ERSP. In the following, validity of this model is examined in detail in the light of physiology. The focus of description is divided into two: the memory and the paralimbic network, and the motor and the prefrontal

network.

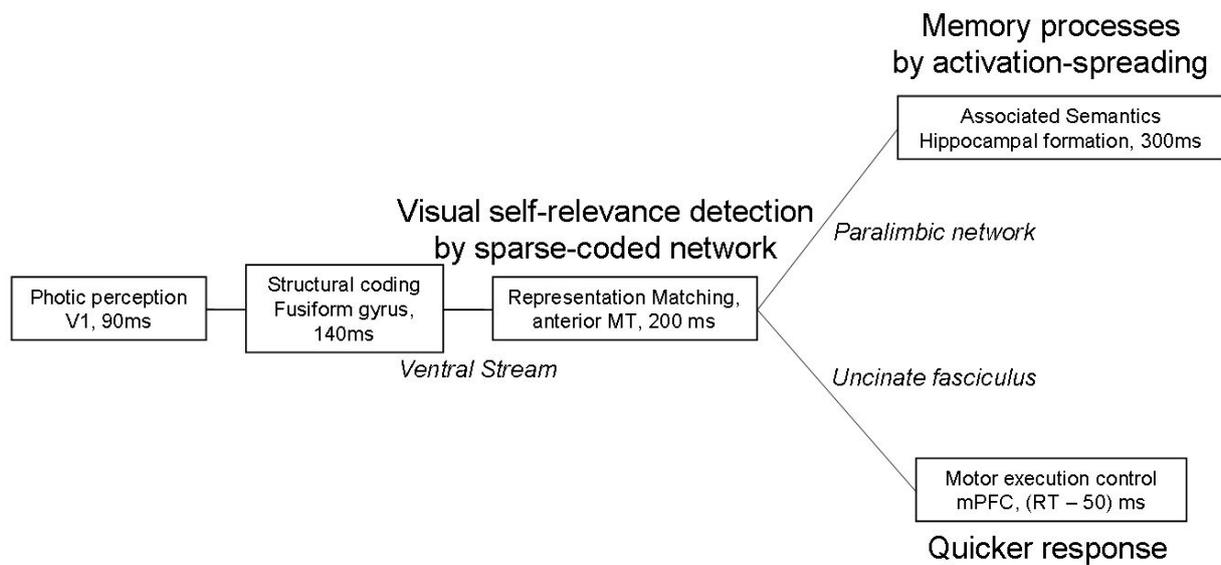


Figure 5.2 The proposed model for illustrating the flow of the initial detection of visual self-relevance.

### 5.3.1 Paralimbic network and sparse coding

We have observed that detection of self-relevance occurs in the ventral stream which is located in the medial temporal lobe (MTL). Physiological research has shown that the ability to recognize a previously experienced visual perception is mediated by two processes: associative recollection and sense of familiarity. Evidence from human and animal neuropsychological, neurophysiological, and neuroimaging studies suggest that the hippocampus and parahippocampal cortex are critical for recollection but not familiarity. Familiarity-based recognition, in contrast, is mediated by perirhinal cortex (Eichenbaum et al., 2007).

The inferotemporal (IT) cortex is involved in higher-order visual processing of complex stimuli such as faces in the fusiform gyrus and scenes in the parahippocampal gyrus. Especially, anterior parts of this ventral stream are dedicated to object perception and recognition. In monkeys, neurons in the upper stages of the ventral stream respond to complex images such as faces and objects and show some degree of invariance to metric properties such as the stimulus size, position and viewing angle (Gross et al., 1969; Miyashita et al., 1988). The same nature of IT was confirmed in humans (Kreiman et al., 2000). This area plays a critical role in object recognition. Importantly, it is established that sparse-coded network is dominantly found in IT (Gross et al., 1969; Gross et al., 1972). Among all, the sparsest codes ever reported was found in human hippocampus (Kreiman, et al., 2000;

Quian-Quiroga et al., 2005). Striking evidence of the nature of sparse-coded neurons was reported by Quian-Quiroga et al. (2005). They found that one of the neurons coded Tower of Pisa and Eiffel tower, and another neuron responded to famous person's face and his/her written name. These results indicate highly abstract and semantic association, which is almost modalityless, is represented by a *single* neuron. Most likely, this is an interneuron that is connected to many neurons and functions as modulator of the local neural ensemble. One may associate it with the grandmother cell hypothesis, which is actually the extreme case of the sparse coding (technically, however, it is practically impossible to prove that certain neuron is exclusively associated with certain representation, for there is too large number of neurons). Such a sparse network as the grandmother cell is the end product of past elaborate computations, and engaging it instead of recalculating the whole processes saves time and energy (Olshausen and Field, 2004).

When considering these physiological evidence, the nature of Recognition Unit revealed by the present research is fairly consistent. The estimated current source of N250 is located within IT, which is specialized for object recognition. The time-course of firing of a highly sparse-coded parahippocampal neuron found by Quian-Quiroga et al. (2005) was 300-600ms. Importantly, the authors emphasized that it is not earlier than this. This latency corresponds to that of P300. This is in line with ERP evidence that face-name priming effect was observed not earlier than P300 (Schweinberger et al., 2004). These are in clear contrast with neuronal activity underlying N250. The time-course of N250 is distinctively earlier (at least by 100ms) than P300, and it is the reflection of cortical activity near IT. The domain-general nature of the highly sparse-coded neuron found by Quian-Quiroga et al. (2005) is also in a clear contrast with the domain-specific nature of Recognition Unit. The early engagement of IT should precede the later domain-general representation in the hippocampal system. The time lag between activations in IT and MTL, or N250 and P300, is relatively long (at least by 100ms), given the time-scale of transmission of neural activation, which could be calculated from ERP results obtained from the Experiment 3. In this experiment, the N170 delay due to ipsilateral hemifield presentation was only 10 ms. It means that within 10 ms, a signal can travel from V1 to the contralateral IT via the corpus callosum (and partly via the posterior commissure). The nearly hundred millisecond of delay may indicate intense neural calculation in the hippocampal system. There is evidence that showed direct synaptic connections between IT and the hippocampal formation (Saleem and Tanaka, 1996). It may take time for input signal to travel within paralimbic network from IT to the hippocampal formation, which may explain possible demand for vision-memory transformation in encoding (Quian-Quiroga et al., 2008).

Based on what reviewed above, the advanced view of N250 can be provided. Bruce and

Young (1986) assumed that Recognition Unit performs the matching process with input information and stored representation. However, now there is evidence that phase-resetting *decrease* is the physiological reflection of this process, which suggests that detecting self-relevance is most likely mediated by activation of the very sparse neural network. It would be interesting to ask why the higher phase coherency is associated for unfamiliar face recognition. The Bruce and Young model does not provide a good explanation for this. One of possible explanations is that phase-resetting actually reflects the ‘encoding effort’ for the novel stimulus, with the same view as Gruber et al. (2005). According to this explanation, phase resetting is less for Self since it is already well-learned, whereas it is more for unfamiliar properties for they need to be newly learned.

It is also important to note here that MT homologue can vary between primate species, and it is one of the regions that underwent most drastic inflation (up to 30 times) compared to macaques (Van Essen and Dirkers, 2007). Notably, these highly inflated areas, including inferior-frontal and inferior-parietal areas, matches the cortical network recruited for exclusive self-face recognition that is distinguished from familiar face recognition (Devue et al., 2007; Kircher et al., 2000, 2001; Platek et al., 2004, 2006; Sugiura et al., 2005a, 2006, 2008; Uddin et al., 2005). This may support the view that visual self-relevance recognition in static image engages highly human-specific cortical networks.

### *5.3.2 mPFC and RT enhancement*

One of the key behavioral features of visual self-recognition is a remarkable RT enhancement. We have already reviewed literature showing involvement of MTL in detecting and representing visual self-relevance recognition. However, it does not provide direct explanation for RT enhancement, and none of previous psychophysiological studies has attempted to clarify the issue. Here, the possible cortical network that mediates RT enhancement triggered by visual self-relevance recognition is focused.

The RT enhancement is usually within a range of 100 ms, which is a too small time-scale for fMRI to resolve, so we again need to refer to EEG literature. In visual selective attention task, Delorme et al. (2007b) found EEG modulation in mPFC that preceded the motor response 25-50 ms. They named this component P3f after Makeig et al. (1999; 2004). They demonstrated the correlation between RTs and P3f amplitude, and concluded that P3f is the manifestation of frontal motor-control process and related to the paralimbic network. This view is compatible with results from the present research, since items that were associated with shorter RTs were associated with larger P300, and P3f occupies the earliest portion of

P300 (P300 is known to be a complex of several components; see Debener et al., 2005). The increased theta power shown in Delorme et al. (2007b) is compatible with the present results, which suggests probable contribution of P3f to P300 also in this study. However, the explanation for the relation between visual information processing in MTL and the motor control in mPFC still remains unclear. This has been the missing link in most of visual paradigms that reported RT enhancement.

There are several major fiber tracts within the brain. The uncinate fasciculus is one of such major fiber tracts. It connects the temporal pole to the basal part of the prefrontal cortex (Figure 5.3). Usually this white matter structure is counted as a part of the limbic system. However, if the visual information analysis is processed in MTL and motor control is mediated in the medial prefrontal cortex, one of the possible neural mechanisms that connect these two may be the uncinate fasciculus. In human, the functional role of this fiber bundle is not well understood. This may be partly because of complex functionality in the connected areas such as temporal poles and orbitofrontal cortex. Taken together, the speculated pathway from visual self-recognition to RT enhancement is that visual self-relevance is first detected in the IT (which elicits N250), which is conducted to both the paralimbic network (which accounts for late P300; not reported in Experiment 3) and the temporal pole; the latter is further transmitted to the motor-control responsible area in mPFC via uncinate fasciculus and triggers the behavioral enhancement, which accounts for the earlier portion of P300 and illustrated in detail in Delorme et al. (2007b).

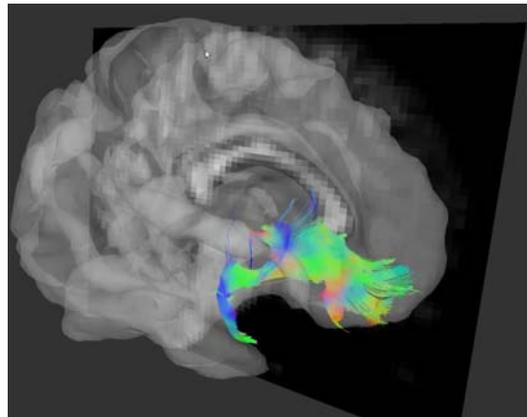


Figure 5.3 Diffusion Spectrogram Imaging<sup>4</sup> (DSI) of uncinate fasciculus. The tracts start from the temporal pole and project to basal part of medial prefrontal cortex.

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<sup>4</sup> n=1, 50 year-old male. Data were acquired with 3T MRI (Magnetom Trio TIM, Siemens). The sequences for DTI were as follows: Slice = 49, FOV = 195mm, Thickness = 2.5mm, TR = 6800/5200ms, TE = 109/94ms, 78x78, GRAPPA with acc.fact. = 2, Ref. line PE = 30, Diff. weights = 2, b-value = 3000/1500, Diffusion direction = 64/30. The high-resolution structural image was acquired with MPRAGE. DSI was calculated with DSI studio (Fang-Cheng Yeh, <http://dsi-studio.labsolver.org/>). Termination criteria were 0.1 for fractional anisotropy and 25 for angle.

#### 5.4 Relation to the concept of the 'Self'

The 'Self' has been one of the most important concepts in various fields of psychology, and one may be interested in the relation between that and the processes of visual self-recognition examined in this thesis. In literature, social psychologists have made primary contribution to reveal the qualitative nature of the 'Self'. For the sake of simplicity, let us divide the concept of the 'Self' into two subconcepts: the 'Self' as conscious processes and unconscious processes. As for conscious processes, it is no surprise that Baumeister (1998) stated that the 'Self' is not really a single topic at all, but rather an aggregate of loosely related subtopics. Leary and Tangney (2003), however, proposed a reasonable simplification of this view by pointing out that virtually all of the conscious processes related to the 'Self' actually involve a capacity for *reflection*, and insisted that it lies at heart of the 'Self'. Thus the recursive nature of the relation, in which a subject of thinking is an object of the thinking, is highlighted as a core phenomenon, and other functionality of the conscious 'Self' is all about its details<sup>5</sup>. Let us adopt this grand view as a tentative definition of the conscious 'Self' here. On the other hand, researchers of unconscious processes related to the 'Self' have stressed how the conscious processes and explicit representations of the 'Self' are actually affected by the unconscious processes. They insist that our thinking and behavior are, to the certain extent, pre-determined by the factors that are hidden from our view i.e. unable to be explicitly aware of by our consciousness (for a readable review, Wilson, 2002). In below, the relation of the visual self-relevance recognition to the conscious processes is discussed first, and to the unconscious processes next.

In considering the relation between visual self-relevance recognition and the conscious processes related to the 'Self', one of possibly critical factors is the evoked subjective awareness of the self-relevance. The present research revealed that visual self-relevance is detected around 200ms post-stimulus (in the earliest case), but it is not clear whether this contributes the generation of the subjective awareness of self-relevance. It is generally hard to underpin exactly when and how the subjective sense or awareness is generated, but for the

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<sup>5</sup> The self-referential nature causes various interesting phenomena in various fields including mathematics, logic, computer programming, grammar in natural language, life sciences, philosophy, music, and painting, as shown in detail by Hofstadter (1979). This comes from the nature of the recurrent system itself. The reflection on oneself also shares this characteristic. This can typically cause the issue of logical confusion when arguing its nature, as Wittgenstein (1922) warned in his early work. Indeed, Leary and Tangney (2003) and Wilson (2002) independently pointed out that there are too many branches (30-70) in the field of the study on the conscious 'Self'. Here, a simple approach is taken to limit the focus on the current issue for the sake of straightforwardness.

sake of exploratory argument let us focus this issue with available evidence including the present research. ERP literature suggests that conscious processes are more likely reflected by P300 than the earlier ERP components. One of examples would be P300 modulation reported in the oddball paradigms, in which the task is to detect a rare target among frequent non-target. ERP studies on the oddball tasks showed that top-down attentional control is dominantly reflected by P300, and no earlier ERP components have ever shown the modulation for the target. From another viewpoint, this evidence also suggests that N250 was not sensitive to task-relevance. The fact that Recognition Unit is insensitive to task-relevance is important because it suggests that top-down guiding of cognitive functions such as attentional control would not engage it. This at least excludes the possibility that Recognition Unit is included in the loop of the recursive process of reflection, which is the tentative definition of the conscious 'Self' here. This consideration leads us to the speculation that psychology of the 'Self' in reflective nature is far in the downstream of cognitive processes from the initial detection of the visual self-relevance.

The other branch of the study on the 'Self' is unconscious processes, which is the next interest of discussion here. As we have seen that conscious processes of the 'Self' would not be very much likely to be related to the visual self-relevance recognition, chances are it operates unconsciously. The results from the experiments in this thesis support this view, and its nature could be now summarized as 1) processed in the relatively early latency, 2) beyond mere sensation and perception, and 3) represented as abstract to a certain extent, but can not be too semantic to become domain-general. Especially, the domain-dependent nature of this process should be emphasized as the opposite view to the conventional explanation of domain-general self-representation. As Northoff and Bermpohl (2006) showed, there is no center of the 'Self' inside the brain, and the network nodes of the 'Self' are actually distributed over the wide areas in the cortex without apparent self-relevant functional modularization. As the results from the current experiments showed, even within a single modality self-relevance is processed differently depending on stimulus domains. This speaks strongly against the view of the 'Self' as a unitary entity. The evidence suggests how the 'Self' is networked and distributed before conscious processes. The conscious 'Self' is founded upon the integration of the various domain-dependent sensory information, and the accessible conscious 'Self' is the result of integration of such sensory information and long-term memories about the two natures, namely the world as an external environment and the unconscious 'Self' as an internal environment.

### *5.5 Limitations in the present research*

It would be of interest whether the visual self-relevance recognition is a generator of subjective awareness of self-relevance as discussed above. This issue was attempted to examine in Experiment 3 by causing anomalous visual self-relevance recognition, but unfortunately the approach was not effective and no positive effect was found. Literature shows that self-relevance recognition in general is centralized to the right hemisphere, and particularly for the case of self-face recognition (which is against the view of the ‘Self’ as non-centralized, distributed networks). Therefore, delivering self-relevant information to the non-dominant hemisphere would have caused, at least theoretically, anomalous visual self-relevance recognition. Under such condition, it may have been possible to clarify what would be the subjective feeling when seeing self-relevant visual stimuli without accessing directly to the core of the processes. One possibility would be that one knows what he or she sees without feeling the awareness of self-relevance. Another possibility would be that he or she shows delayed reaction time for detection but with unaffected subjective awareness of the visual self-relevance. It is hard to determine which case is true without performing empirical studies. In order to clarify this issue, the same approach but with a different technique, such as transcranial magnetic stimulation (TMS), seems still a good idea. By interfering neuronal activities during 200-300ms poststimulus near fusiform gyrus with TMS, and the role of the initial visual self-relevance recognition to the subjective awareness could be studied.

### *5.6 Concluding Remark*

In the present research, visual self-recognition with static images, which is considered to reflect highly human-specific ability, was investigated. A series of experiments provided empirical evidence that support the conclusion that visual Self is detected domain-dependently (especially self-face is preferably processed) and represented beyond-perceptually. The detection occurs in IT, and its time-course is around 200-300ms poststimulus. It is associated with decreased EEG phase-resetting, which suggests engagement of sparse-coded networks. The sharpening process that takes place during past experiences would be responsible for such a sparse-coding mechanism. Based on these findings, the new psychophysiological model of visual self-recognition was proposed. The model covers from the initial detection of visual self-relevance to its effect on motor output. In the model, two cortical network nodes, IT and mPFC, play critical roles. Functionality and the chronoarchitecture of IT and mPFC were highlighted in Experiment 3. These provide

further detail and empirical supports to the Bruce and Young model. Visual self-recognition highly depends on functionality of MTL, which is specially evolved in human. It suggests the association of high intelligence of human beings and visual self-recognition.

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