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Suppression of 12-Hz SSVEPs when viewing familiar faces: An electrophysiological index to detect recognition

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ABSTRACT

Criminal investigation often involves finding out what a suspect knows about people, such as victims and confederates, who are involved in the crime. This study explored the possibility of determining a person's recognition of other individuals by analyzing the steady-state visually evoked potentials (SSVEP) triggered by visual oscillations of familiar and unfamiliar faces. In our study, 23 adult (10 men) participants gave subjective familiarity ratings (in a 7-point Likert scale) of > 300 celebrities' and strangers' faces. For each participant, ten familiar and ten unfamiliar faces were selected based on his/her ratings. The selected faces were presented at 6 Hz while the participants performed a color change detection task orthogonal to the attributes of faces. The task was designed to maintain participants' visual attention towards the faces throughout the stimulus oscillations. Any difference between conditions would indicate modulation of visual attention by face familiarity. Results showed that the 12-Hz event-related spectral perturbations (ERSPs in decibel) at parietal-occipital electrodes were significantly lower when viewing familiar faces compared to unfamiliar faces. In individual level analysis, 18 out of 23 (78%) participants had significantly lower 12-Hz ERSPs at left parietal-occipital ROI in familiar face than unfamiliar face trials. This is the first study to demonstrate that SSVEPs triggered by stimulus oscillations can reveal people's recognition of faces with only 20 trials per condition and 10-s for each trial.

1. Introduction

Crime investigation often involves finding out what a suspect knows about the details of the crime and the persons involved. For example, an investigator may want to find out whether a suspect dishonestly denied his/her relationship with a known terrorist. Developing an objective tool to reveal whether a person recognizes a face can be useful for police investigation. This is the goal of the present study, and the index we propose for this purpose is the SSVEP. As we will develop below, our study aimed to fill the knowledge gap by comparing the differences in SSVEP when individuals perceived familiar versus unfamiliar faces.

Regarding the underlying mechanism of face processing, a model was proposed by Bruce and Young (1986) that structural configuration of a face is first analyzed in the structural encoding stage. The processing then diverges into two routes, one for processing stable attributes related to identity serving face recognition, and the other for processing dynamic facial attributes such as emotional expression and gaze. In the face recognition route, the “face recognition units” contain perceptual representations of familiar faces, and the “personal identity nodes” contain semantic information related to a person, such as name and relationship. The sequence of face processing stages, which include first structural encoding and then face recognition and facial attributes analysis, was supported by previous event-related potential (ERP) studies which captured the precise timing of brain responses to face processing. Findings have shown that N170, a negative-going ERP peaking at around 170 ms after stimulus onset at occipito-temporal sites, is related to early structural encoding of faces (Bentin and Deouell, 2000; Eimer, 2000; Sagiv and Bentin, 2001). While the amplitude of N170 is enhanced by viewing faces compared to non-face stimuli or scrambled faces, it is insensitive to familiarity of a face (Tanaka et al., 2006; Jemel et al., 2003), irrespective of task relevance (Bentin and Deouell, 2000). Later ERP components were found to be sensitive to recognition of familiar faces: familiar faces elicited a larger amplitude of N250 (e.g. Tanaka et al., 2006), N400 (Bentin and Deouell, 2000; Paller et al., 2000) and frontocentral positivity at 550 ms (Henson et al., 2003). These results suggest that N170 is related to structural encoding (Puce

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et al., 1999) and processing of face familiarity occurs at a later stage after the structural encoding stage is completed.

Although past studies have examined the ERP correlates of face familiarity processing, none of the previous studies have investigated the effect of *face familiarity* on SSVEP. SSVEPs are electrophysiological responses recorded from the scalp oscillating at the same frequency as the stimulus presentation, and its higher harmonics are often triggered as well (Regan, 1966). For example, a visual stimulus flickering at 15 Hz generates a 15 Hz sinusoidal waveform of SSVEPs with highest amplitudes at parietal-occipital sites (Wieser and Keil, 2011). SSVEPs are believed to originate from synchronous extracellular currents along the pyramidal neurons' apical dendrites in the extrastriate visual cortex (Pastor et al., 2003), and maximum amplitudes recorded on scalp are usually seen at parieto-occipital and ventrolateral regions depending on the frequency and stimulus types (Müller et al., 1997). The SSVEP has the advantage of higher signal-to-noise ratio and less influence by artifacts due to eye blinking and movement compared to the conventional ERP paradigms, and reliable results can be obtained within a relatively short experimental duration (Morgan et al., 1996). For example, a study reliably detected larger SSVEP responses to face identity changes with only 90-s of stimulation per condition (Rossion and Boremanse, 2011). Another SSVEP study with emotionally arousing stimuli showed that a single trial analysis with stimulus duration of 6 s resulted in reliabilities (Cronbach's Alpha) of 0.8 across electrodes (Keil et al., 2004). These characteristics make SSVEP a potential candidate for usage in real-life criminal investigation settings which require higher signal-to-noise ratios because of less possible experimental control.

To the authors' knowledge, there are only four recent studies examining how stimulus familiarity modulates SSVEP (Kaspar et al., 2010; Koenig-Robert and VanRullen, 2013; Martens et al., 2012a; Martens et al., 2012b). The studies consistently found that SSVEP is sensitive to object recognition. For example, in Kaspar et al. (2010), recognizable objects flickering at 7.5 Hz elicited smaller SSVEP amplitudes in occipital areas than unrecognizable objects. However, all these studies examined how object recognition (i.e. the existence of object representation) influences SSVEP, and they compared recognizable stimuli (e.g. every-day objects) to unrecognizable stimuli (e.g. nonsense or degraded stimuli). The research question of whether variation in the level of familiarity towards *recognizable* stimuli, particularly faces, modulates SSVEP remains unknown. In other words, it is still uncertain whether viewing familiar faces lead to enhanced or reduced SSVEP responses, which imply increased and decreased visual attention respectively. Our study aimed to fill this knowledge gap by comparing the differences in SSVEP when individuals perceived familiar versus unfamiliar faces.

In our study, face stimuli were presented at 6 Hz half-wave rectified sinusoid while participants performed a color change detection task orthogonal to the stimulus familiarity but designed to maintain their eye fixation and visual attention throughout the face presentations. The stimulus frequency of 6 Hz was chosen because a previous study has shown that individual face discrimination was performed most optimally at 6 Hz compared to other stimulus frequencies which ranged between 1 and 16.66 Hz (Alonso-Prieto et al., 2013). In that study, the SSVEP responses to faces over occipital-temporal areas were largest at 6 Hz of stimulus presentation. Importantly, the 6 Hz cycle fit with the latency of the N170 component which indexes face discrimination (Bentin et al., 1996). The authors argued that at higher frequency of presentation (> 6 Hz), individual face discrimination (which takes around 170 ms) could become impossible because the rapidly presented subsequent stimulus disrupts the processing of the previous one (Alonso-Prieto et al., 2013). One should note that stimulus presentation at 6 Hz would presumably elicit a 6 Hz SSVEP which falls within the range of Theta rhythms (4–7 Hz). Importantly, theta activity, which originates in hippocampus, was found to be related to recognition memory (Jacobs et al., 2006) and control of working memory processes (Scheeringa et al., 2009). Since familiar faces are associated with richer semantic content, we hypothesized that familiar faces would tap on greater working memory resources and trigger enhanced bottom-up visual attention, resulting in larger 6 Hz SSVEP responses as compared to unfamiliar faces.

On the other hand, the second harmonic (12 Hz) of oscillation falls within the alpha frequency band (8–12 Hz). In general, alpha activity was traditionally believed to be associated with an idling mental state, disengagement, or a default mode of inactive brain areas as its amplitudes are heightened when eyes are closed and diminished when eyes are opened (e.g. Krause et al., 1996; Pfurtscheller et al., 1996). However, evidence has also supported that alpha-band activity serves inhibitory function linking to suppression and selection of attention (Klimesch, 2012). For example, alpha power at visual-related occipital channels was enhanced when the task required attention focus on the auditory component (instead of the visual component) of a compound auditory-visual stimulus (Foxe et al., 1998). Other studies using a visuospatial attention task also showed that occipital alpha activity increased if the corresponding hemifield was ignored as a task requirement (Kelly et al., 2006; Medendorp et al., 2007; Worden et al., 2000). Therefore, visual stimuli (such as familiar faces) that attract bottom-up attention are supposed to be associated with alpha suppression.

Apart from inhibition of attention to perceptual stimuli, alpha-band activity was also found to be related to long-term memory access (see Klimesch, 2012 for a review). A decrease in alpha-band activity was associated with an increase in the ability to selectively access information from long-term memory that represents the meaning of sensory stimuli, a process termed “semantic orientation” (Klimesch, 1999, 2011). For example, a decrease in upper alpha power was found during the time window of picture recognition in a previous study (Freunberger et al., 2008). Past studies on how face recognition relates to alpha oscillations are scarce. Burgess and Gruzelier (1997) studied recognition memory of faces and words by analyzing epoch-averaged EEG. Participants showed suppression of alpha, beta1, and beta 2 during recognition of faces but not words, as compared to acquisition phase. Another study by the same group examined memory-related changes in EEG by analyzing event-related desynchronization (Burgess and Gruzelier, 2000). In a recognition task, compared to new faces, previously presented faces (of strangers) elicited greater desynchronization at left temporo-parietal sites for lower alpha and the same effect was on the right side for upper alpha activity. Please note that the face stimuli used in Burgess and Gruzelier (2000) were all novel to the participants before the experiment while the familiar stimuli in our study were celebrities' faces.

We believed that the semantic knowledge associated with familiar faces but not with unfamiliar faces was a key difference between experimental conditions in our study. We therefore hypothesized that familiar faces, which are associated with richer semantic content, would trigger decreased 12 Hz (alpha-band) EEG responses as compared to unfamiliar faces. The analysis of EEG response differences between familiar and unfamiliar face condition was conducted in both group data and individual subject's data.

2. Methods

2.1. Participants

Twenty-six adults (11 men) participated in this experiment. Two participants' data were excluded due to experimenter error (of setting a wrong sampling rate) and one was excluded because of excessive artifacts. The final data set contains 23 participants' (10 men) data. A power analysis was conducted with reference to the effect size (Cohen's $d = 0.64$) found in Kaspar et al. (2010) which examined object familiarity with SSVEP measures. Based on an analysis using the G*Power software, we found that a sample size of 22 participants would be sufficient to detect an effect with 80% power at the 0.05 significance level using a 2-tailed paired sample *t*-test.