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Semantic processing in subliminal face stimuli: An EEG and tDCS study

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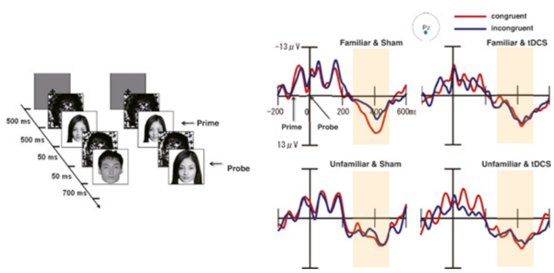
HIGHLIGHTS

- The purpose of this study was to examine the subliminal processing pathways.
- We examined the effect of modulation with tDCS to the prefrontal cortex.
- Priming effect toward famous primes vanished after tDCS stimulation.
- Subliminal process proceeds to semantic level in the prefrontal area.

GRAPHICAL ABSTRACT



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ABSTRACT

Whether visual subliminal processing involves semantic processing is still being debated. To examine this, we combined a passive electroencephalogram (EEG) study with an application of transcranial direct current stimulation (tDCS). In the masked-face priming paradigm, we presented a subliminal prime preceding the target stimulus. Participants were asked to determine whether the target face was a famous face, indicated by a button press. The prime and target pair were either the same person's face (congruent) or different person's faces (incongruent), and were always both famous or both non-famous faces. Experiments were performed over 2 days: 1 day for a real tDCS session and another for a sham session as a control condition. In the sham session, a priming effect, reflected in the difference in amplitude of the late positive component (250–500 ms to target onset), was observed only in the famous prime condition. According to a previous study, this effect might indicate a subliminal semantic process [10]. Alternatively, a priming effect toward famous primes disappeared after tDCS stimulation. Our results suggested that a subliminal process might not be limited to processes in the occipital and temporal areas, but may proceed to the semantic level processed in prefrontal cortex.

1. Introduction

Visual stimuli below the threshold of awareness, called subliminal stimuli, affect our emotions and behavior. Since a reliable methodology for subliminal priming was established and the effect of subliminal stimuli was proven in the 1990s (see Kouider and Dehaene [15] for a review), the differences in processing visual stimuli, whether aware or unaware of their perception, have become an important topic of study in cognitive neuroscience. The elucidation of visual awareness may be a key to improving understanding of cognitive disorders.

The study of visual awareness can be performed through either elucidation of the mechanism of stimuli perceived with conscious awareness, termed supraliminal, or the elucidation of the visual mechanism of subliminal stimuli. For supraliminal stimuli, it is known that the generally visual process of supraliminal stimuli starts from the occipital brain area responsible for low-level processing, such as contrast processing, and then proceeds to the frontal brain region responsible for high-level processing, such as semantic processing. Alternatively, the mechanism for subliminal visual processing is still being debated. According to Dehaene et al. [5], a subliminal visual stimulus is imperceptible because the visual

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process associated with this stimulus does not reach the prefrontal cortex. Contradicting this theory, were some reports claiming that visual processing of subliminal stimuli might actually proceed to high-level processes in the prefrontal cortex. Since visual word processing involves semantic processing, the occurrence of a priming effect with subliminal words would support the assertion that subliminal processing actually involves a semantic process. Some studies on visual word stimuli found a priming effect in subliminal priming [6,14,16]. However, even if the entire word is not correctly perceived, it is possible that participants might see some letters in the word and be partially primed (for a review, see [4]). Hence, subliminal visual word priming is not a strong enough demonstration to prove the subliminal semantic process [1].

A common paradigm for subliminal studies is the priming paradigm with visual masking, in which the supposedly subliminal stimulus is presented very briefly (50 ms or shorter), followed by a normally perceived stimulus. Between the first and second stimuli, a visual mask is presented to interrupt the visual process of the first stimulus, making it unperceivable [13]. Generally, when the prime (first stimulus) and the target (second stimulus) are congruent (exactly identical objects in perceptual priming, belong to the same category in conceptual priming, and semantically related in semantic priming), the visual process of the prime will enhance the process of the target following it. In contrast, when the prime and target are incongruent (irrelevant or contradict each other) the enhancement does not occur or an inhibition effect may occur in some cases (for a review, see [7]). This enhancement or inhibition variance according to prime-target congruency generally results in behavioral or electrophysiological differences (reaction time, ERP amplitude, and latency), which is called a “priming effect” and can be used to examine subliminal processing.

A lexical decision task in associative or semantic priming paradigm is commonly used to investigate semantic processing. In this kind of study, the N400 component serves as electrophysiological index of the effect as its amplitude is known to be magnified when prime and target are semantically incongruent (e.g., [8,11]). As mentioned above, it is controversial whether lexical priming effect is reliable for stimuli presented subliminally. Therefore, we used faces of famous and non-famous people as experimental stimuli instead. Faces are known to hold semantic information, especially, famous faces automatically trigger retrieving knowledge about the person regardless of task demand [2].

In our study combining subliminal priming paradigm and transcranial direct current stimulation (tDCS), there is a disadvantage of using the N400 as index of subliminal priming effect (the reason will be clarified later in this paper). According to previous lexical priming and face repetition priming studies, the centroparietal late positive component (LPC) is interpreted to be functionally similar to N400 (e.g., [9,19]). Therefore, we used LPC as electrophysiological index of semantic processing.

As mentioned above, several subliminal stimuli studies, performed passively, could not answer the question of whether or not subliminal processing involves semantic processing clearly. To obtain more clarity on the subject, we used a transcranial direct current stimulation (tDCS) to modulate the frontal area, which is thought to be responsible for semantic processing, and observed the correlations reflected in both a behavioral index and electroencephalography. tDCS is a stimulation technique involving a weak constant electric current to modulate the excitability of a particular brain area. A number of studies employing tDCS have reported that the modulation tDCS on several brain regions such as motor, somatosensory, and visual cortices in human (for a review, see [20]) can be observed in both electrophysiological and behavioral indices. Generally, cathodal stimulation inhibits cortical excitability and results in suppression of brain function of the area stimulated. Anodal stimulation gives the opposite result.

The purpose of this study was to examine whether semantic processing occurs in subliminally presented stimuli. This is possible by monitoring subliminal priming effect reflected in LPC before and after suppressing activation in the anterior DLPFC (dorsolateral prefrontal cortex). The hypothesis was that, if the process for subliminally presented stimuli involves semantic processing, a correlation could be demonstrated between altered activity in the anterior DLPFC and changes in the subliminal priming effect in LPC. In the present study, we chose to monitor effect that can be observed in parietal sites (LPC) instead of anterior sites (N400) where cathodal electrode was placed. This was to avoid the possibility that any change in electrophysiological signal measured from anterior sites near tDCS electrode might be a mere change in cortical excitability from electrical stimulation.

2. Experimental procedures

2.1. Participants

This study involved 14 participants (mean age: 24.79 y; range: 22–39 y; 11 men) with no severe visual disorders. Myopic and color blind subjects were not included in the study. Before the experiments were commenced, it was confirmed that all participants knew the famous faces used throughout the questionnaire. Among the 14 participants, 3 participants did not pass the visibility test and were excluded from EEG and reaction time (RT) analysis. One participant was also excluded from the analysis because of insufficient trials due to artifacts in EEG. Informed consent was obtained from participants after details of the procedure had been explained to them. The experimental procedures were approved by the Committee for Human Research of Toyohashi University of Technology.

2.2. Stimuli

Face stimuli used in the experiment were all frontal views of Japanese faces in grayscale, normalized by mean luminance and contrast. The average luminance of each stimulus was 61.72 cd/m^2, and the average contrast (RMS) was 42.58. Forty famous faces and 80 non-famous faces were used. The proportion of male and female faces in the stimuli remained consistent. Prime stimuli were 6 degrees and target stimuli were 8 degrees in size. Twenty masks were created from 4 face images and block noise was used. Experiments were carried out in a dark room with magnetic shield. Stimuli were presented on CRT display (FlexScan T766, Eizo Nanao Corp., Hakusan, Ishikawa, Japan, 800 × 600 resolution, frame rate 100 Hz) and apparent distance was 75 cm.

2.3. Experimental procedure

The experiments were performed over 2 days according to tDCS stimulation conditions—1 day for sham or actual stimulation. On each day, we performed visibility tests to ensure that participants would not be able to perceive the subliminal prime face, before tDCS stimulation and after EEG recording sessions. After the first visibility test, the tDCS stimulation was delivered by a battery-driven, constant current stimulator using a pair of surface saline-soaked sponge electrodes (5 cm × 5 cm) (Eldith DC-stimulator PLUS, neuroConn GmbH, Ilmenau, Germany). A direct current of 1 mA intensity was applied for 20 min, complying with current safety guidelines [17,18]. The cathode electrode was placed on the anterior left DLPFC (corresponding to position of electrode F3 in the 10–20 international EEG coordinate system) and the anode on the right temporal area (corresponding to position of electrode T6 in the 10–20 international EEG coordinate system). The tDCS session was followed by 2 EEG recording sessions with a short break. One session was divided into 2 tasks, the masked paradigm and the