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The influence of stimulus onset asynchrony on neuronal suppressive phenomenon in face processing: An event-related potential study

Mingdi XU and Keiji Iramina, *Member, IEEE*

***Abstract*—It has been reported that if two sensory stimuli are presented consecutively with stimulus onset asynchrony (SOA) of as short as several hundreds of milliseconds, the neural activity, elicited by the second stimulus, in the stimulus-sensitive area will be inhibited, say, suppressive phenomenon. Using a paired-stimulus paradigm, in which two visual stimuli were successively presented, we investigated the influence of SOA (200ms, 400ms & 600ms) on suppressive phenomenon in face processing. Twelve subjects were asked to passively view randomly ordered paired stimuli and single stimuli, while their event-related potentials (ERPs) were recorded simultaneously. To evaluate the suppression, we compared the ERPs elicited by the second face stimulus of the paired stimuli with that elicited by the single face stimulus. It was found that, comparing with the ERPs elicited by single faces, in all three SOA conditions, the ERPs elicited by the second face stimulus of the intra-category trials (face_face trials) were more suppressed than those of the inter-category trials (blank_face and building_face trials) in both occipitotemporal and frontal regions. We surmised that these results might support a "domain specific" theory, which suggested that visual processing of faces and non-face objects involve separate and specialized networks in the ventro-lateral temporal cortex. Interestingly, for the face_face trials, as the SOA increased, the ERP suppression in the frontal region diminished gradually. Such phenomenon might be due to the lasting effect of semantic processing for the first face stimulus.**

I. Introduction

It was found that suppressive phenomena of neural origin occur when a preceding stimulus reduced the system electrophysiological response to the subsequent stimulus at the same site, and this suppression might happen when the stimulus onset asynchrony (SOA) is less than a few seconds [1]. Some neuroscientists explained that such suppression stems from neuronal interactions that occur while processing two inputs, when some portion of the neuronal circuits are shared or these circuits are close enough in space to influence each other [2]. This kind of suppressive phenomenon has been observed in both event-related potential (ERP) and fMRI signals of the primary auditory [1], somatosensory and visual cortices [2, 3]. However, how does the SOA influence the suppressive phenomenon remains unclear. Here we focused on this issue in face processing in the human brain.

According to the well-known hierarchical model for visual information processing, visual input experiences early perceptual and structural encoding and is then allocated to a certain object category and further processed in a specialized object recognition system [4, 5]. Given the importance of human faces in social communication, the heated issue upon whether faces and other non-face objects are processed by common or specific neuronal circuits has drawn the interest of numerous neuroscientists [6]-[9].

For information processing of visual inputs of different categories, due to the limitation in the temporal/spatial resolution of the measurement instrument, it is difficult to determine whether they are processed by separate and specialized neuronal "modules" [10] or by a large network of overlapping visual regions in a distributed manner [7, 11]. In order to investigate the brain activity at the neuronal circuit level and to elucidate the characteristics that determine the functional roles of certain brain regions, a novel paired-stimulus paradigm, in which two sensory inputs are presented successively without any intervening items, was designed and frequently used in fMRI studies [2, 3, 12]. Nevertheless, the influence of consecutive stimulus presentation with same or other category on visual information processing was seldom discussed [13].

Therefore, the purpose of the present study was to investigate the temporal aspects of suppressive phenomenon as a result of successive stimuli presentation, and to examine the characteristics of certain brain regions for processing faces information, at a neuronal circuit level. Specifically, we recorded the ERPs of twelve subjects during passive viewing of faces, buildings or gray-colored blank images, using stimulus pairs of: inter-category pairs (**blank_face** and **building_face** trials) and intra-category pairs (**face_face** trials, with faces of different persons). With the same stimulation conditions, we investigated the influence of SOA on suppressive phenomenon.

II. Materials and Methods

A. Subjects

Twelve right-handed students from Kyushu University (2 female; age: 22–28) with normal or corrected-to-normal vision participated in the experiment. None of them have history of neurological disease. Two of them were excluded because of technical problems in data acquisition. The experiments were conducted with the understanding and the written consent of each participant, and were formally approved by the ethical committee of Kyushu University.

Mingdi XU is with the Graduate School of Information Science and Electrical Engineering, Kyushu University, 744 Motooka Nishi-ku, Fukuoka 819-0395, Japan. (Tel:+81-92-802-3767; Fax: +81-92-802-3581; e-mail: jyo@bie.is.kyushu-u.ac.jp)

Keiji Iramina is with the Graduate School and Faculty of Information Science and Electrical Engineering, Kyushu University, 744 Motooka Nishi-ku, Fukuoka 819-0395, Japan. (Tel & fax: +81-92-802-3581; e-mail: iramina@ inf.kyushu-u.ac.jp).

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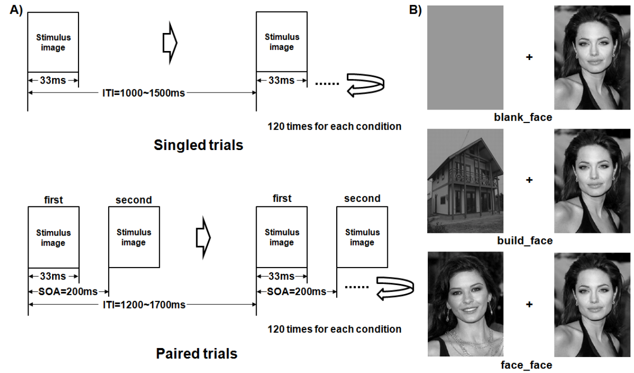

Fig.1. A) Time sequence of the experiment. B) Examples of the 3 types of paired stimuli: blank_face, build_face & face_face. For ease of description, "build" instead of "building" was used.

B. Materials and Stimuli

Gray-colored blank image and gray-scaled pictures of 200 unfamiliar buildings and 100 faces of Hollywood movie stars were used as the visual stimuli; all software edited using Adobe Photoshop7.0. Each image was framed within an area of 230 pixels wide × 325 pixels high (8×10cm), forming visual angle of 7.2°×5.7°. An attempt was made to homogenize the stimuli with respect to average luminance and contrast. The experiment was programmed and carried out with STIM2 (NeuroScan), and consisted of separate single trials (**blank, build, face**) and paired trials (**blank_face, build_face, face_face**), as described in Fig.1. For the **face_face** trials, two different faces were always set to be of same sex. A total of 120 trials of each condition were presented. In order to prevent predictive value of the forthcoming stimulus, all trials were shown in pseudorandom order. Throughout the experiment, self-paced breaks were allowed after every 120 critical trials.

C. EEG recording

In a dimly lighted and electrically-shielded room, the subjects were seated in a comfortable chair. A fixed chin-rest was used to maintain a constant viewing distance of 800mm from the CRT monitor (Flexscan T561). The subjects were instructed to do nothing but to view the stimuli passively. During EEG acquisition, the subjects were instructed to relax and avoid any eye or body movements, as much as possible.

Table.1. Mean ratio (R) and standard errors (SE) of P100'/P100 in percentage at PO7 and PO8, when SOA=200ms.

Condition	R±SE (PO7)	R±PE (PO8)
blank_face/face	82.1±24.7	83.8±29.2
build_face/face	81.3±10.5	71.4±11.4
face_face/face	54.4±13.9	54.7±15.5

Table.2. Mean ratio (R) and standard errors (SE) of P170'/P170 in percentage at F3 and F4, when SOA=200ms.

Condition	R±SE (F3)	R±PE (F4)
blank_face/face	75.3±17.0	80.5±18.1
build_face/face	60.9±9.7	62.4±9.4
face_face/face	26.8±11.9	26.7±11.0

EEG was recorded using 64 electrodes mounted in an electrode cap according to the extended international 10/20 system. The impedance of all electrodes was kept below 10kΩ. The signals were recorded continuously with a band-pass ranging from 0.16 to 120Hz and digitized at 1000Hz (Nihon Kohden Neurofax 1000). Offline, EEG data was re-referenced to the ears-averaged reference, and digitally low-pass filtered at 30Hz. Trials contaminated with eye-blinks or other artifacts (≥100μV) were initially excluded with automatic software (BESA 5.2) and further visually checked. For each subject, accepted trials from the same condition were averaged in each specific channel. Then the averages of trials calculated for each condition over each channel, for each subject independently, were averaged for all the subjects. Averaging Epoch was set as -100ms to 1000ms after stimulus onset.

III. RESULTS

We defined the positive component appeared at the occipito-temporal region around 80-130ms after stimulus onset as P100 for single stimulus (control), and P100' for the second face stimulus of the paired stimuli; the negative component appeared at the occipito-temporal region around 150-180ms after stimulus onset as N170 for single stimulus, and N170' for the second face stimulus of the paired stimuli; similarly, its positive counterpart at the frontal region as P170 and P170', respectively.

The ERPs elicited by the second face stimulus of the paired stimuli *(blank_face, build_face & face_face*) were estimated from the ERPs elicited by the paired stimuli *(blank-face, build-face & face-face)* and the single stimulus (*blank, build & face)*. That is, for the **blank_face** trials, *blank_face = blank-face – blank*; for the **build_face** trials, *build_face = build-face – build*; for the **face_face** trials, *face_face = face-face – face*. In order to view the suppressive phenomenon directly from the ERPs waveforms, we compared the ERPs elicited by *blank_face, build_face & face_face* with the ERP elicited by *face*. Specifically, we corrected the baseline of *blank_face, build_face & face_face*, for each condition respectively, by subtracting the value at the time-point of second stimulus onset from the whole data (obtained from the above equations), and then shifted them by

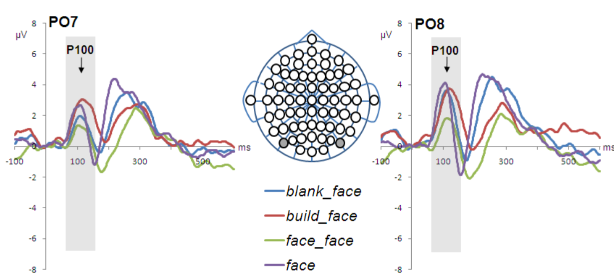

Fig.2. Grand averaged ERPs elicited by the second face stimulus of the paired stimuli (*blank_face, build_face, face_face*), as well as the control single face stimulus (*face*), from two selected occipito-temporal electrodes (PO7 and PO8), when SOA=200ms. Arrows with P100 indicate the initial ERP suppression. It can be observed that, the suppression in *face_face* was more significant than those in *blank_face* and *build_face*.

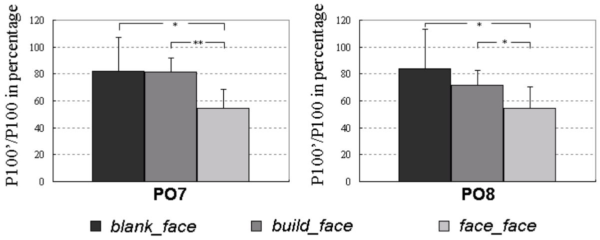

Fig.3. Suppression of P100' component elicited by the second face stimulus of the paired stimuli (*blank_face, build_face, face_face*), comparing with the P100 component elicited by the single face stimulus, at electrodes PO7 and PO8, when SOA=200ms, as indicated by P100'/P100 in percentage. It can be observed that the suppression of P100' component of *face_face* was larger than those of *blank_face* and *build_face* (*P<0.05; **P<0.01).

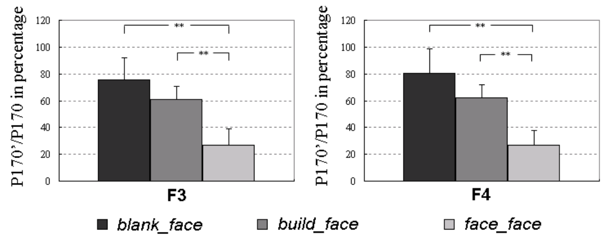

Fig.5. Suppression of P170' component elicited by the second face stimulus of the paired stimuli (*blank_face, build_face, face_face*), comparing with the P170 component elicited by the single face stimulus, at electrodes F3 and F4, when SOA=200ms, as indicated by P170'/P170 in percentage. It can be observed that the suppression of P170' component for *face_face* was much more significant than those for *blank_face* and *build_face* (*P<0.05; **P<0.01).

length of SOAs to have the same stimulus onset point with *face*.

To quantitatively examine the suppressive phenomenon, for each condition, we calculated the ratio (R) of P100' or N170'/P170' amplitude relative to P100 or N170/P170 amplitude in percentage, i.e., R= *blank_face/face or build_face/face or face_face/face* (as shown in Table.1&2). As illustration, the calculation was performed when SOA=200ms only.

Fig.2 showed the grand averaged ERPs elicited by the control single face stimulus (*face*) and the second face stimulus of the paired stimuli (*blank_face, build_face, face_face*), at selected occipitotemporal electrodes PO7 and PO8, when SOA=200ms for example. It can be observed that, the ERP suppression emerged already at the P100 stage. Comparing with the P100 component elicited by *face*, the amplitude of P100' component elicited by *face_face* decreased more obviously than that evoked by *blank_face* and *build_face*. Mean ratio of P100' relative to P100 and standard errors for each condition were shown in Table.1. There was significant difference (P<0.05) between *blank_face* and *face_face* at both PO7 and PO8, and there was also significant difference between *build_face* and *face_face*, (P<0.01) at PO7 and (P<0.05) at PO8, as shown in Fig.3.

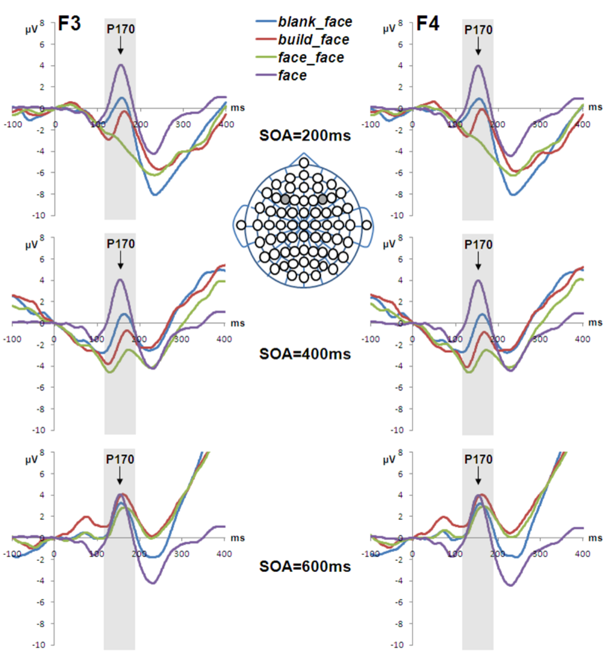

Fig.4. Grand averaged ERPs elicited by the second face stimulus of the paired stimuli (*blank_face, build_face, face_face*), as well as the control single face stimulus (*face*), from two selected frontal electrodes (F3 and F4), when SOA=200ms, 400ms and 600ms. Arrows with P170 indicate the suppression effects. It can be observed that when SOA=200ms, the suppression effect in *face_face* was much more remarkable than those in *blank_face* and *build_face*. Most importantly, for the *face_face* trials, as the SOA increased, the suppression in P170 diminished gradually.

Fig.4 showed the grand averaged ERPs elicited by the control single face stimulus (*face*) and the second face stimulus of the paired stimuli (*blank_face, build_face, face_face*), at selected frontal electrodes F3 and F4, when SOA= 200ms, 400ms and 600ms. It was found that, when SOA=200ms, comparing with the P170 component elicited by *face*, the amplitude of P170' component elicited by *face_face* was suppressed much more remarkably than those elicited by *blank_face* and *build_face*. Most interestingly, for the *face_face* condition, when the SOA=400ms, the P170' component slightly increased; and when the SOA=600ms, the P170' component recovered to a large degree. Quantitative evaluation of the ERP suppression was done when SOA=200ms as illustration; mean ratio of P170' relative to P170 and standard errors for each condition were shown in Table.2. There were significant differences (P<0.01) both between *blank_face* and *face_face* & between *build_face* and *face_face*, at both F3 and F4, as shown in Fig.5.

IV. Discussion

It has been reported that if two sensory stimuli are presented consecutively with a short inter-stimulus interval (several hundreds of milliseconds), the brain activity, evoked by the second stimulus, in the stimulus-sensitive area will be inhibited [3]. Taking the present SOA of 200ms, 400ms and 600ms into consideration, any decrement in ERP amplitudes in response to the target stimulus might be indicative of reduced neuronal activity induced by successive stimulation.

A "domain specific" theory [6], which postulated that visual processing of faces and non-face objects involve separate and specialized networks in the ventro-lateral temporal cortex might lend support to the present results, especially when the following notions are considered simultaneously. Although not precise, by source analysis, previous ERP studies indicate that the main neural generator of the N170/P170 component lies in the lateral occipito-temporal cortex [14]. Moreover, neuroimaging studies have identified both a face-specific area (FFA: fusiform face area) and a place-specific area (PPA: parahippocampus place area) in this region [10, 15]. Thus, it is plausible that the N170 elicited by faces and buildings might both originate from the lateral occipito-temporal cortex, but from different neuron population networks located in the FFA and PPA. As demonstrated in a neural adaptation study, neuronal activity reduced when two successive stimuli activate the same subpopulation but not when they stimulate different ones [16]. With respect to the present study, in *face_face*, both the prime and target stimuli belong to the face category. Thus, one may postulate that they should activate the face-selective neuronal populations in the FFA to a similar degree. In contrast, in *build_face*, the prime and target stimuli might elicit the activity of at least partially distinct neuron populations, in the FFA and PPA. To put it differently, the increased perceptual distance between the prime and target stimulus in *build_face* could be physiologically reflected by a narrower overlap of neural activity relative to *face_face*, which will in turn cause more variation in neural responses and lead to a larger brain potential consequently.

Furthermore, as shown in the present results, the influence of SOA on suppressive phenomenon was prominent at the N170/P170 stage in the frontal regions (F3, F4). Most interestingly, in the *face_face* trials, when SOA=200ms, the P170 component almost disappeared. As an explanation, because faces of familiar Hollywood movie stars were used, although the SOA was very short, the subjects might involuntarily associate some identity information related to the celebrities (as reported by the subjects after experiments). In contrast, they reported no similar experiences for unfamiliar buildings and meaningless blank image in the *build_face* and *blank_face* trials. In addition, it is widely accepted that in the human brain, face recognition and semantic processing is achieved at about 250ms after stimulus onset [17]. In the present study, with SOA of 200ms, at the time of second face stimulus onset, the face recognition system might have been processing the first face stimulus. Since only one face can be processed at a time, as recently suggested of a limit in face-specific attentional capacity [18], it might be reasonable to suppose that the strong suppression of frontal P170' component in the *face_face* trials would be due to inadequate processing of the second face stimulus.

On the other hand, it might be also possible that an ERP component is not a unitary cortical response, multiple cerebral generators, spatially or temporally overlapping, may contribute to a single ERP peak recorded at the scalp. Therefore, we hypothesized that, even though the P170' component at F3, F4 remained significant, at this latency (if we take the onset of the first stimulus as starting point, then at latency of SOA+170ms = 200ms+170ms = 370ms), other generators such as those relating to post-perceptual semantic processing for the first face stimulus, possibly N400 [9], might have contributed to the negatively going tendency of the P170'component. As the SOA increased (up to 400ms and 600ms), the overlapping effect of N400 decreased accordingly, and the P170' component recovered gradually as a result. To clarify this interesting phenomenon, further investigation is needed in future study.

V. CONCLUSION

In this study, with paired stimulus paradigm, a suppressive phenomenon has been observed not only in the occipito-temporal area, but also in the frontal area of the brain. In both areas, the ERP suppression in the *face_face* trials was more remarkable than in the *blank_face* and *build_face* trials. We supposed that these results might support a "domain specific" theory. Interestingly, for the *face_face* trials, when SOA=200ms, the frontal P170 component elicited by the second face stimulus almost disappeared. As the SOA increased, the P170 suppression diminished gradually. Such phenomenon might have relationship with the lasting effect of semantic processing for the first face stimulus.

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