Perceptual Similarity between Pictures Modulates ERPs during a Stop/NoStop Task

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Similarities between stimuli affect performance on reaction time (RT) tasks. This study examined whether similarities between pictures modulate stimulus-elicited event-related brain potentials (ERPs) during a Stop/NoStop task, in which participants had to withhold motor responses. The Stop/NoStop task is a relatively novel method of assessing discriminative RTs, in which participants are asked to withhold a motor response to a particular stimulus (Stop trials), but to respond to all other stimuli (NoStop trials). Stimulus similarity was manipulated by varying the perceptual similarity between the Stop stimuli and the NoStop stimuli. ERPs for Stop stimuli were recorded during both low- and high-similarity conditions. These new data were analyzed along with data previously collected during a medium-similarity experiment (Akamine & Kida, 2006). The Stop stimuli elicited a large central-parietal dominant positive wave (late P3), with a peak latency of about 400–550 ms. Late P3 latency significantly increased as a function of stimulus similarity, but amplitude did not change. This component closely resembles the NoGo P3, which is related to response inhibition. Difficulties in discriminating between the stimuli would cause a delay in the inhibition of responses to the Stop stimuli. In addition, RTs for NoStop stimuli increased as a function of stimulus similarity. These results suggest that the stimulus processing that is required if a motor response is to be withheld might have a reciprocal relationship with response execution in a discriminative RT task.

Keywords: event-related brain potentials, P2, N2, P3, Stop/NoStop task, response inhibition

In various cognitive tasks, participants' performance (e.g., reaction times (RTs), error rates) vary according to the nature of the experimental manipulation, including physical stimulus properties, the probability of stimulus occurrence, and the degree of similarity across stimulus categories. In order to perform a task successfully, it is important to accurately process not only the target stimuli (i.e., a participant is required to pay attention and usually to execute a motor response), but also any non-target stimuli (i.e., a participant is required to withhold a motor response to such stimuli). However, there are very few investigations of the relationship between cognitive processing of target and non-target stimuli. Moreover, how the two types of processing influence each other remains unclear. We recorded event-related brain potentials (ERPs) during a discriminative reaction time task in the present study, to examine the cognitive processing of a stimulus for which a motor response is withheld.

ERPs have served as a valuable tool for investigating the brain activity that underlies information processing in humans. One particularly useful aspect of the ERP technique is that it enables processing activities to be studied even when the individual does not perform an overt response. ERPs thus overcome a limitation of behavioral measures such as RTs, the recording of which necessitates observable responses.

NoGo P3

The Go/NoGo task is a familiar cognitive task in ERP research. In this task, participants are required to identify Go (target) stimuli and respond (e.g., pressing a button), whereas they are not required to detect NoGo stimuli and to make a motor response. The classic P3 (P3b) elicited by Go stimuli has had its maximum amplitude at the more posterior scalp sites. In contrast, the NoGo response has a somewhat longer latency and a more frontal-central distribution than the target-related P3, and this component is often referred to as the NoGo P3, to distinguish it from the classic P3 (Eimer, 1993; Fallgatter & Strik, 1999; Jodo & Inoue, 1990; Strik, Fallgatter, Brandeis, & Pascual-

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Marqui, 1998). Because these topographies remain constant across visual and auditory modalities, both the Go P3 and NoGo P3 have been described as having a modality independent nature (Tekok-Kilic, Shucard, & Shucard, 2001). Topographical differences between Go and NoGo conditions suggest that these ERPs do constitute two separate components: Each corresponds to a distinct neural generator, and these components appear to be produced by functionally distinct brain systems (Pfefferbaum & Ford, 1988). Indeed, the Go P3 has been related to target detection or response production (Eimer, 1993; Pfefferbaum, Ford, Weller & Kopell, 1985), whereas the NoGo P3 has been associated with response inhibition (Schupp, Lutzenberger, Rau, & Birbaumer, 1994; Strik et al., 1998). NoGo P3 is a slow positive variation without a clear peak. Although many researchers have described P3 (P3b) latencies, we could not find a study that had examined NoGo P3 latencies.

Using Go/NoGo and Stop/NoStop tasks, we examined the effects of negative emotions on RTs and ERPs (Akamine & Kida, 2005) . We have also investigated ERPs associated with stimulus presentations when participants withheld motor responses in the experiment (Akamine & Kida, 2006). The Stop/NoStop task is a discriminative reaction time task in which participants are required to withhold a motor response to a particular stimulus (Stop trials), but to respond to all other stimuli (NoStop trials). Both NoGo and Stop stimuli elicit two large positive components, termed early P3 and late P3. These are observed around 300 ms and 500 ms after stimulus onset, respectively. The amplitude of the early P3 increases from Fz to Pz, and does not appear to differ across NoGo and Stop stimuli. On the other hand, the late P3 has a central-parietal distribution and is notably larger for Stop stimuli than for NoGo stimuli. The late P3 elicited by Stop stimuli exhibits a clear peak. However, such a clear peak has not been observed during processing of NoGo stimuli. It has been suggested that the early P3 should be equivalent to the P3b, and that the late P3 should be equivalent to the so-called NoGo P3 (e.g. Jodo & Inoue, 1990). Thus, early P3 appears to be related to stimulus evaluation, whereas late P3 seems to reflect aspects of response inhibition (Schupp et al., 1994; Strik et al., 1998).

As briefly mentioned above, in the Stop/NoStop task it is crucial that participants judge whether an incoming stimulus is a Stop stimulus or not. It is expected that the Stop stimulus would capture participants' attention and would activate various cognitive processes, including both perceptual and response processes. However, participants are required to withhold a motor response to the Stop stimulus. To prevent the implementation of a motor response, the participants would need to resolve the cognitive conflict between perceptual and response processes that is produced by the task instructions. Thus, it has been suggested that the large late P3 elicited by Stop stimuli reflects effortful inhibition of activated response processes (Akamine & Kida, 2004, 2006). One would expect that investigating the late P3 elicited by Stop stimuli would provide somewhat different findings for response inhibition.

Purpose of the Present Study

It was assumed that degree of similarity between picture stimuli would cause difficulty in stimulus discrimination. The present study was designed to examine the effects of difficulties in stimulus discrimination on cognitive processes activated by a stimulus that requires a motor response to be withheld, i.e., a Stop/NoStop task. ERPs for Stop stimuli were recorded during two experimental conditions, employing the same methodology as used in our previous study (Akamine & Kida, 2006). In this previous study, five categories of pictures (cars, people, flowers, electronics, and landscapes, with probability of 0.4, 0.3, 0.1, 0.1 and 0.1) were used, and the car stimuli were assigned to be the Stop stimuli. Here, the car stimuli were replaced with simple geometric shapes in Experiment 1, and with animals in Experiment 2. Experiment 1 served as the low-similarity condition and Experiment 2 as the high-similarity condition. The previous experiment in which the car stimuli were used as the Stop stimuli was defined as the medium-similarity condition for present purposes. Degree of similarity between picture stimuli was manipulated based on the degree of perceptual similarity between Stop and NoStop "people" stimuli, which were presented most frequent in the NoStop stimuli. ERPs elicited by the Stop stimuli across these three conditions were analyzed here.[1]

Experiment 1 [2]

Method

We used a similar method to that of Akamine and Kida (2006).

Participants

Twenty-one students at Aichi Gakuin University (15 women and 6 men, M age = 22.2 years) participated in the study for payment. None of them had participated in our previous study (Akamine & Kida, 2006).

Procedure

Stimuli. Five groups of color pictures were used in this study: Simple geometric shapes, people, flowers, electronics, and landscapes. Except for the simple geometric shapes, these pictures were the same as those used by Akamine and Kida (2006). The simple geometric shapes category consisted of 20 different images (e.g., circle, triangle, square). The people category included 10 different ordinary faces (neutral stimuli) and 10 different faces that featured some type of skin disease or external injury (negative stimuli). The remaining three categories (flowers, electronics, and landscapes) consisted of 5 pictures each.

Stimuli were presented one at a time on a computer screen that was positioned approximately 1 m in front of the participants. Each picture subtended a visual angle of 14.0° horizontally and 10.0° vertically, and was presented with a fixed stimulus onset asynchrony of 3,000 ms (500 ms on and 2,500 ms off).

Reaction time task. Participants performed a Stop/NoStop task. The five categories of pictures, simple geometric shapes, people, flowers, electronics, and landscapes were presented randomly with probabilities of 0.40, 0.30, 0.10, 0.10, and 0.10, respectively. The participants were required to respond to all pictures except for geometric shapes by pressing a button with the index finger of their right hand, as quickly and accurately as possible. Following 50 practice trials, all participants performed 300 experimental trials, which consisted of six blocks with 50 trials each.[3]

ERP Recording and Data Collection

Electrophysiological data were collected during the discriminative reaction time task. Electroencephalograms (EEG) were recorded from four midline sites, Fz, Cz, Pz, and Oz, referenced to linked earlobes. An electrooculogram (EOG) was recorded from an electrode located below the right eye. Electrode impedances did not exceed 10 kOhms. EEG and EOG signals were amplified using the San-ei 360 system (filter bandpass: 0.05 (time constant 3 s) –30 Hz). The data, together with trial information, were stored on a magnetic tape and processed offline. All recordings were digitized at 500 Hz. ERP waveforms were computed for each participant by averaging readings for the epoch from 200 ms before stimulus onset to 1,000 ms after stimulus onset. Averaged ERPs were obtained for the Stop geometric shape stimuli at each electrode. The trials on which eye movements or blinks occurred and those with an incorrect or no response were excluded from the ERP averages. The averaged ERPs were aligned to a 200-ms pre-stimulus baseline.

Experiment 2

Method

We used the same method as in Experiment 1. The differences between Experiments 1 and 2 were as follows:

Participants

Thirteen students at Aichi Gakuin University (10 women and 3 men, M age = 21.4 years) participated in the experiment for payment. They had not participated in Experiment 1 or Akamine and Kida (2006).

Procedure

Stimuli. Animal pictures, 20 different images of monkeys', dogs' and cats' faces, were used instead of simple geometric shapes. The other pictures were the same as those used in our previous experiments.

Reaction time task. The participants' task was to press a button in response to all pictures except the animals (i.e., people, flowers, electronics, and landscapes) with the index finger of their right hand, as quickly and accurately as possible.

ERP Recording and Data Collection

ERP waveforms were obtained for each participant and site, in response to the Stop animal stimuli.

Results

The purpose of the present study was to examine whether stimulus similarities modulate ERPs for Stop stimuli. To this end, the data collected in our previous study (Akamine & Kida, 2006[4]) were newly analyzed and compared with the data obtained in the present Experiments 1 and 2.

Behavioral Data

Mean error rates and RTs for each task condition are shown in Table 1. Although the Stop stimuli induced more errors than did the NoStop stimuli, participants made very few errors overall.

RTs for the 5 categories of NoStop stimulus were averaged for each participant and submitted to a one-way analysis of variance (ANOVA), with Stop stimulus similarity level as the independent variable (low-, medium-, and high-similarity). A significant effect of similarity was obtained, $F(2, 62) = 11.90$, $p<.01$. A Tukey's *HSD* test revealed that RTs were shortest in the low-similarity condition, followed by the medium-similarity condition and then the high-similarity condition, $HSD(3, 62) = 31.68$, $p<.001$.

Table 1: Mean Error Rates (%) and Reaction Times (ms)

		Stop stimuli	NoStop stimuli					
			Neutral people	Negative people	Electronics	Flowers	Landscapes	*M*
Error rate								
Low-similarity condition		(Geometric shapes)						
	M	3.37	0.20	0.12	0.04	0.08	0.20	0.13
	SD	2.60	0.72	0.39	0.18	0.35	0.51	0.34
Medium-similarity condition		(Cars)						
	M	5.27	0.19	0.13	0.13	0.08	0.13	0.13
	SD	3.70	0.89	0.48	0.60	0.32	0.48	0.51
High-similarity condition		(Animals)						
	M	3.08	0.13	0.13	0.13	0.13	0.06	0.12
	SD	2.18	0.44	0.30	0.30	0.30	0.22	0.21
Reaction time								
Low-similarity condition								
	M	—	362.2	363.8	389.9	370.5	376.8	372.6
	SD	—	48.7	48.1	54.3	53.2	50.7	49.7
Medium-similarity condition								
	M	—	384.9	406.5	452.0	390.7	406.1	408.0
	SD	—	36.2	38.6	33.2	41.8	41.1	35.1
High-similarity condition								
	M	—	469.0	467.7	473.3	466.8	487.6	472.9
	SD	—	102.3	95.7	94.5	89.3	107.3	96.2

ERP Data

P3. Figure 1 shows grand-mean waveforms for the Stop stimuli. The early components (N1, P2 and N2) show a front-central distribution. These were followed by an extremely large positive deflection (P3) that appeared after 300 ms, with a central-parietal distribution. The P3 component was designated as the largest positive deflection, peaking between 300 and 630 ms after the N1–P2–N2 complex. The peak latency and baseline-to-peak amplitude of P3 were measured for each averaged ERP. The data at Oz had to be excluded from analysis due to the indistinct waveforms obtained from many of the participants; analyses were performed only on data collected from Fz, Cz, and Pz. These data are shown in Table 2.

P3 peak latency data were submitted to a two-way ANOVA, with Stop stimulus similarity (low-, medium-, and high-similarity) and site (Fz, Cz, and Pz) as independent variables. Both main effects of Stop stimulus and site were significant, $F (2, 62) = 29.17$, $p<.001$; $F (2, 124) = 4.48$, $p<.05$, respectively. The two-way interaction was not significant. A Tukey's *HSD* test revealed that P3 latencies were significantly different across all conditions, *HSD* (3, 62) = 30.25, $p<.05$. Latencies were shortest in the low-similarity condition, followed by the middle-similarity condition and then finally the high-similarity condition. In addition, P3 latencies at Fz were significantly longer than
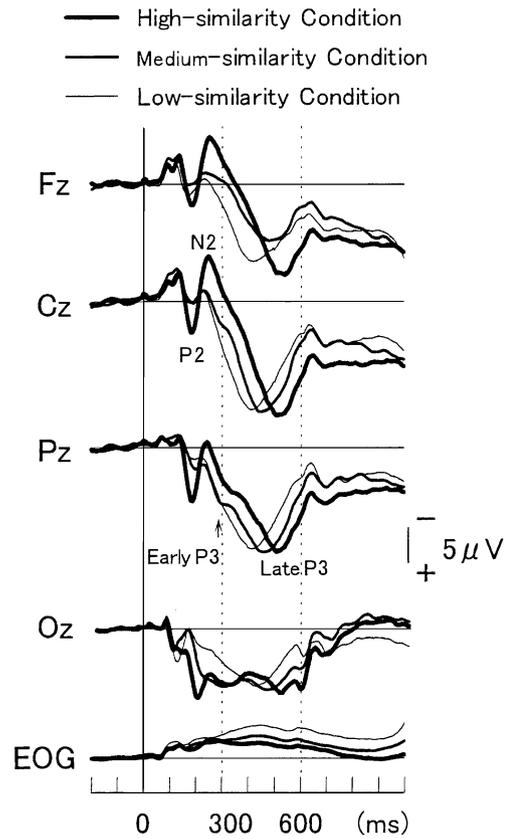

Figure 1: Grand mean ERPs elicited by Stop stimuli

Table 2: Mean latencies and amplitudes of late P3 for the Stop stimuli

		Latency (ms)			Amplitude (μV)		
		Fz	Cz	Pz	Fz	Cz	Pz
Low-similarity condition							
	M	434.1	420.9	421.3	12.72	17.54	16.16
	SD	47.9	39.6	40.4	4.60	6.66	6.24
Medium-similarity condition							
	M	485.9	463.8	458.8	9.78	16.89	16.11
	SD	45.5	40.0	49.9	5.43	8.13	6.46
High-similarity condition							
	M	532.0	527.8	530.6	14.31	17.91	16.38
	SD	40.9	41.0	46.2	7.34	8.18	6.63

they were at Cz and Pz, HSD (3, 62) = 12.49, $p<.05$. There was no latency difference between Cz and Pz.

The same two-way ANOVA was also performed on the P3 peak amplitude data. The main effect of site was significant, F (2,124) = 53.38, $p<.001$, whereas the main effect of Stop stimulus similarity was not significant. A significant Stop stimulus similarity x Site interaction was obtained, F (4, 124) = 3.66, $p<.01$. However, while the simple main effects of Stop stimulus similarity were not significant at each electrode site, the simple main effects of site were significant at each level of Stop stimulus similarity. A Tukey's HSD test revealed that P3 amplitudes were significantly larger at Fz than at Cz and Pz, HSD (3, 124) = 2.15, $p<.05$; however, in the high-similarity condition, Fz < Pz, $p<.10$. No significant amplitude differences between Cz and Pz were found.

P2 and N2. The baseline-to-peak amplitudes of the P2 and N2 components were measured at Cz, within ranges of 120–220 and 180–300 ms, respectively. Participants' data were removed from further analysis if no clear P2 and/or N2 peaks could be observed on their ERP waveforms. The following analyses were performed on the data of 56 participants: 17 in the low-similarity condition, 26 in the medium- similarity condition, and 13 participants in the high-similarity condition. Table 3 presents the amplitudes

Table 3: Mean amplitudes of P2 and N2 at Cz for the Stop stimuli

		P2	N2
Low-similarity condition			
	M	0.96	–3.59
	SD	4.31	4.27
Medium-similarity condition			
	M	2.43	–3.51
	SD	4.20	3.19
High-similarity condition			
	M	4.78	–7.50
	SD	2.93	5.53

of the P2 and N2 components at the Cz site. These were submitted separately to one-way ANOVAs with Stop stimulus similarity as the independent variable.

The analysis of the P2 amplitude data showed a significant effect of Stop stimulus similarity, F (2, 53) = 3.41, $p<.05$. A Tukey's HSD test showed that P2 amplitudes were significantly larger in the high-similarity condition than in both the low- and medium-similarity conditions. There were no differences between the low-similarity and medium-similarity conditions, HSD (3, 53) = 1.88, $p<.05$.

Finally, the N2 amplitude data also showed a significant effect of Stop stimulus similarity, F (2, 53) = 4.55, $p<.05$. N2 amplitudes were significantly larger in the high-similarity condition than in the low- and medium similarity conditions, but there were no significant differences between the low- and medium similarity conditions, HSD (3, 53) = 2.49, $p<.01$.

Discussion

In the present study, the largest positive peaks elicited by the Stop stimuli, with a latency range of 300–600 ms after stimulus onset, were examined. The components were distributed at the central-parietal site. Akamine and Kida (2006) demonstrated that this positive deflection is equivalent to late P3. The late P3 is also similar to the NoGo P3 that is associated with response inhibition (e.g., Jodo & Inoue, 1990). A terraced positive wave was seen in the medium and high-similarity conditions studied here, around 300 ms after stimulus onset at the parietal site. These components would be equivalent to P3b (or early P3). P3 yielded by Stop stimuli would consist of at least two distinct components. In contrast, a remarkably large single positive peak could be seen in the low-similarity condition. It is possible that Stop stimuli in the low-similarity condition would also elicit the two types of positive components with a latency range of 300–600 ms

after stimulus onset. The two components occurred very closely together in temporal space. As a result, they might have overlapped strongly and ultimately merged into a single large compound component (Falkenstein, Koshlykova, Kiroj, Hoormann & Hohnbain, 1995).

RTs for NoStop stimuli increased as a function of stimulus similarity. In addition, the latency of the late P3 significantly increased along with stimulus similarity, but amplitude did not change in a similar fashion. Thus, difficulty in discriminating between stimuli would cause not only a delay in reaction times to the NoStop stimuli, but also a slowdown in the process of response inhibition to the Stop stimuli. Although the putative connection between changes in late P3 latency for Stop stimuli and RTs for NoStop stimuli needs further examination, it is suggested that processing of the stimuli to which a motor response must be withheld might have a reciprocal relationship to response execution in a discriminative reaction time task. Hasher and Zacks (1988) proposed an inhibition deficit hypothesis, such that age-related impairments result from a weakening of inhibitory processes. Studies focused on these inhibitory processes would be valuable for investigating human information processing activities.

Both P2 and N2 were considerably larger in the high-similarity condition than in the low- and medium-similarity conditions. In the high-similarity condition, the pictures of animals' faces were used as Stop stimuli, with cars and simple shapes serving as medium and low similarity stimuli, respectively. Rockstroh, Elbert, Birbaumer, & Lutzenberger (1982) reported that the N100–P200 complex showed large amplitudes when participants' attention was shifted to the evoking stimulus. It is assumed that the N100, and possibly the P200, reflect the initial selection of an information source for further processing. The present study suggests that facial images are more likely to capture participants' attention at an early stage after stimulus onset.

Several studies have suggested that N2 for NoGo stimuli is related to response inhibition (Eimer, 1993; Jodo & Kayama, 1992; Kok, 1986; Pffeerbaum et al., 1985). Other studies have demonstrated that the negative deflection around 250 ms after stimulus onset is enhanced in response to pictures of persons' faces (Akamine & Kida, 1998; Watanabe, Okita, Konishi, & Imashioya, 1998). Pictures of people yield larger N2 than pictures of cars, on both Go and NoGo trials (Akamine & Kida, 2000). Thus, the enhancement of N2 in the high-similarity condition might be closely related to the detection of faces (human or animal), rather than response inhibition.

Notes

1 ） We presented this study at the 72nd Annual Convention of the Japanese Psychological Association in September 2008, at Hokkaido University.

2 ） We thank Keita Kogura, a graduate of Aichi Gakukin University, for his help with Experiments 1 and 2.

3 ） We presented the study, which examined the differences in RTs and ERPs between NoStop negative and neutral stimuli, at the 25th Annual Convention of the Japanese Society for Physiological Psychology and Psychophysiology in July 2007, at Sapporo Medical University.

4 ） Thirty-one students at Aichi Gakuin University (22 women and 9 men, *M* age = 21.8 years) participated in the study for payment.

Akamine and Kida (2006) examined two subcomponents of P3: Early P3 and late P3. The early P3 amplitude was designed as the mean waveform amplitude during the 50–ms period between 290 and 340 ms. Late P3 amplitude was designed as the mean waveform amplitude during the 50–ms period between 460 and 510 ms. In the present study, ERP data obtained by Akamine and Kida (2006) were re-analyzed using the same procedure used in Experiments 1 and 2.

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