Neuropsychologia 47 (2009) 2604–2614

Contents lists available at ScienceDirect

Neuropsychologia

journal homepage: www.elsevier.com/locate/neuropsychologia

The impact of negative attentional set upon target processing in RSVP: An ERP study

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ARTICLE INFO

Article history:
Received 29 September 2008
Received in revised form 31 March 2009
Accepted 14 May 2009
Available online 22 May 2009

Keywords:
Attentional blink
Attentional set
RSVP
ERP
N2pc
N2

ABSTRACT

This study investigates whether the negative attentional set, a form of top-down attentional bias, can be set up on a trial-by-trial basis and impair online target processing in an RSVP (Rapid Serial Visual Presentation) task in which two targets are to be identified. Using the N2pc (N2 posterior contralateral) – a component in the event-related potential (ERP) evoked by lateralized targets – as an index of attentional selection, we demonstrated that the online processing of the second target (T2) can be inhibited by a category-specific negative attentional set elicited by a special distractor (D1) prior to the first target (T1) and that this attentional set can be set up at an abstract, conceptual level. A digit T2 was presented on the left or right following a central RSVP letter stream which had a unique red letter T1. Another digit or a Chinese number character was presented prior to T1 as D1, which had to be ignored. Relative to the D1 absent condition, either type of D1 impaired T2 performance and delayed the N2pc response to T2. D1 elicited a frontocentral N2 peaking at about 300 ms post-onset of D1, suggesting that D1 is indeed an inhibition-evoking stimulus. A further behavioral experiment ruled out the possibility that D1 impairs T2 performance via attentional capture or a category-unspecific, general negative attentional set.

1. Introduction

Human beings are exposed to constantly changing sources of information over time, but only some of which are relevant to our current goals or intentions. To perform efficiently, our brain may adopt different attentional sets for selecting information. These attentional sets are a form of top-down control, which increases the efficiency and flexibility to deal with the world around us.

Besides the positive (excitatory) attentional set that biases attention towards stimuli with specific properties, the negative (inhibitory) attentional set that biases attention away from stimuli with particular properties, plays an important role in our daily life. The operation of both positive (e.g., Chelazzi, Miller, Duncan, & Desimone, 1993; Mangun, Buonocore, Girelli, & Jha, 1998) and negative (e.g., Cepeda, Cave, Bichot, & Kim, 1998; Chen, Zhang, & Zhou, 2007; Tipper, 1985, 2001; Watson & Humphreys, 1997) attentional sets in human performance has been demonstrated in many previous studies. What these studies have in common is that targets and task-irrelevant distractors are typically presented at the same time but at different locations. Relatively little is known about the operation of attentional sets when targets and distractors are presented at different times (but see Folk, Leber, & Egeth, 2008; Maki & Mebane, 2006; Olivers & Watson, 2006). A useful way to investigate attentional selection over time is the attentional blink (AB) paradigm (Broadbent & Broadbent, 1987; Raymond, Shapiro, & Arnell, 1992), in which identification of the second of two targets (T1 and T2) in an RSVP (Rapid Serial Visual Presentation) stream is impaired when the targets are presented at a target onset asynchrony (TOA) of 200–500 ms.

How the attentional set operates in the AB has been considered in recent years to be a crucial question in understanding the mechanisms of the AB (e.g., Di Lollo, Kawahara, Ghorashi, & Enns, 2005; Nieuwenstein, 2006; Olivers & Meeter, 2008; Olivers, van der Stigchel, & Hulleman, 2007; Olivers & Watson, 2006; Visser, Bischof, & Di Lollo, 2004). It has been hypothesized that when observers search for targets in an RSVP stream, a positive attentional set is employed to enhance the encoding of target stimuli, together with a negative attentional set to restrict the encoding of distractor stimuli. The role of positive attentional set in RSVP tasks has been demonstrated, for example, by Nieuwenstein, Chun, van der Lubbe, and Hooge (2005), Nieuwenstein (2006), and Zhang, Shao, and Zhou (2007). In these studies, T2 performance is enhanced when T2 is pre-cued by distractors having the same

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doi:10.1016/j.neuropsychologia.2009.05.008

color (and thus matching the target-defined attentional set) as the target.

Similarly, the negative attentional set may play a role in actively suppressing task-irrelevant distractors (e.g., Loach & Mari-Beffa, 2003; Maki & Padmanabhan, 1994; Olivers & Meeter, 2008; Olivers et al., 2007). For example, Maki and Padmanabhan (1994) used an AB task in which T1 was a white letter and T2 was a black digit among black letter distractors. The target digit was shown at the beginning of each trial. Participants were instructed to remember this digit and decide whether it was presented in the RSVP stream, in addition to detecting the T1 letter. They performed this task

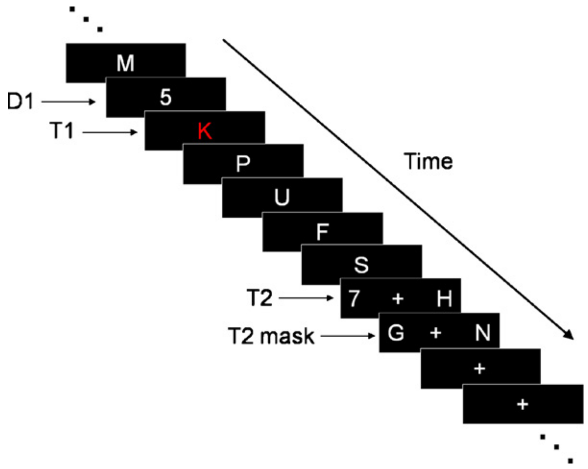

Fig. 1. A schematic representation of the trial procedure in Experiments 1 and 2. Each item was presented for 100 ms, with no blank interval between consecutive items.

before T1, and D1 at lag −3 in which D1 was presented as the third item preceding T1. For each critical condition, T2 appeared at the left or right to the fixation with equal probability (100 trials for each side in each D1 condition). Two types of filler trials were intermixed with the critical trials. There were 100 filler trials in which an RSVP stream consisted of only letter distractors (i.e., without D1, T1, and T2) and 100 filler trials in which only D1 and distractors were presented. A letter distractor replaced T2 at the left or right location in the filler trials. In total, there were 800 trials for each participant, divided over 20 blocks. In addition, there were 24 practice trials before the formal experiment.

The participant sat comfortably about 1 m in front of a computer screen in a sound-attenuated room and held a bi-handle joystick with both hands for manual response. Stimuli were presented on a CRT monitor with a refresh rate of 100 Hz. The participant pressed a button on the joystick with right thumb to initiate each trial. A central fixation cross was presented for 1 s, followed by the RSVP stream. D1 and T2 were Arabic digits, drawn from the set of 2–9, whereas distractors were uppercase letters (excluding “D”, “I”, “O”, “Q” and “Z”; see Fig. 1). D1 and T2 were never the same digit in a trial.

All stimuli were presented in white against black background except T1, which was a unique red letter. T1 was presented with equal probability as the 7th to 11th item of the RSVP stream. Each RSVP item was presented for 100 ms and it subtended about 0.3° × 0.4° in visual angle. D1, T1, and letter distractors were all presented at the center of the screen. However, T2 and an accompanying contralateral letter distractor, about 4° away from each other, were presented on either side of the fixation sign (“+”) which occupied the central position. T2 always appeared as the 5th item following T1 (i.e., TOA = 500 ms). The subsequent stimulus frame contained two masking distractor letters at the locations of T2 and its accompanying distractor. After these masks, the central fixation sign was presented for another 600–1000 ms such that the total stream of stimuli lasted 2200 ms. After the RSVP stream, a string of 8 letters was presented and the participant had to indicate which letter corresponded to T1 by horizontally moving a cursor under the letters using a left or right button located on the front of the bi-handle joystick. Then a string of 8 digits was presented and the participant had to indicate, in the same way as for T1, which digit corresponded to T2. Participants were instructed to respond as accurately as possible. Feedback concerning the correctness of choice was provided immediately after each target response. The identification task was not conducted for the filler trials.

There were three reasons for us to use a fixed time interval (i.e., lag 5, TOA of 500 ms) between T1 and T2, rather than to use a variable TOA between them, as in most AB experiments. Firstly, in previous experiments (Zhang, Zhang, Zhou, & Martens, submitted for publication). see also Experiment 3 in this paper, we found that both the Arabic and the Chinese D1 affected T2 performance throughout the range of time intervals between T1 and T2, from lag 1 to 8. Secondly, lags during which the AB effect appears to be the largest (e.g., lag 2 or 3) are not optimal for investigating the N2pc to T2. According to previous studies (e.g., Jolicoeur et al., 2006), the N2pc to T2 is suppressed when T2 is close to T1 (e.g., at lag 2) than when T2 is further away from T1 (e.g., at lag 8). Finally, the use of lag 5 allowed us to examine the P300 to T1, without it distorting (or being distorted by) the ERP responses to T2.

2.1.3. ERP recording

The EEG was recorded using 64 Ag–AgCl electrodes attached to an elastic cap (NeuroScan Inc. Herndon, VA, USA) according to the International 10/20 system (Japser, 1958). The vertical electrooculogram (VEOG) was monitored from electrodes located above and below the left eye and the horizontal EOG (HEOG) from electrodes located at the outer canthus of each eye. The AFz electrode on the cap served as ground. Recordings were referenced to the left mastoid. Electrode impedances were kept below 5 kΩ. To minimize the EOG artifacts, participants were asked to avoid eye blinks and eye movements during the period of fixation and presentation of the RSVP stream.

The biosignals were amplified with a band pass from 0.01 to 100 Hz and digitized at 250 Hz. The EEG data were re-referenced offline to linked electrodes by subtracting one-half of the activity recorded at the right mastoid from each sample of data recorded at each channel. The data were filtered offline using a 30 Hz low-pass filter to remove high-frequency waves. Finally the data were baseline corrected and averaged to create ERPs.

2.1.4. Data analysis

All trials in which EEG voltages exceeded a threshold of $\pm 75\,\mu$V during the recording epoch were excluded from further analysis. Trials with incorrect responses to either T1 or T2 were also excluded from averaging. In this way, 28.9%, 34.6%, and 33.5% of the 200 trials were excluded for the D1 absent, D1 at lag −1 and D1 at lag −3 conditions, respectively. Following this procedure, each ERP data point for each participant was based on 50 trials or more.

To make sure that D1 is indeed an inhibition-evoking stimulus, ERP responses to D1 were extracted for D1 present trials from 200 ms before to 600 ms after the onset of D1, with the 200 ms pre-D1 period for baseline correction. ERP responses to letter distractors at lag −1 or lag −3 positions in the critical D1 absent trials were also time-locked in the same manner as ERP responses to D1. They served as baselines for the D1 comparisons. For statistical analyses, ERP responses on the following 30 electrodes were averaged into 15 electrode pairs: C3/CP3, C4/CP4, C5/CP5, C6/CP6, Cz/CPz, F3/FC3, F4/FC4, F5/FC5, F6/FC6, Fz/FCz, P3/PO3, P4/PO4, P5/PO5, P6/PO6, and Pz/POz. Difference waves for D1 present minus D1 absent conditions were analyzed to avoid the contamination from T1-evoked and distractor-evoked ERP responses. The peak negativity of the N2 component was determined in a time window of 200–450 ms after stimulus onset.

ERP responses to T1 were extracted over an epoch from 500 ms before to 500 ms after the onset of T1. Because in some trials D1 was presented at −300 ms before the onset of T1, the period of −500 to −300 ms was used for baseline correction, to avoid the baseline being contaminated by activities evoked by D1. For statistical analyses, ERP responses on the following 30 electrodes were averaged into 15 electrode pairs: C3/CP3, C4/CP4, C5/CP5, C6/CP6, Cz/CPz, F3/FC3, F4/FC4, F5/FC5, F6/FC6, Fz/FCz, P3/PO3, P4/PO4, P5/PO5, P6/PO6, and Pz/POz. The peak of the P300 was determined in a time window of 200–500 ms after T1 onset.

ERP responses to T2 were extracted over an epoch from 200 ms before to 600 ms after the onset of T2, with the 200 ms pre-T2 period for baseline correction. Lateralized activity for T2 was monitored at posterior sites (P3/4, P5/6, P7/8, PO3/4, PO5/6, and PO7/8). The N2pc and the SPCN were calculated by subtracting the average activity recorded on electrodes ipsilateral to T2 from the average activity recorded on electrodes contralateral to T2. For each participant, the peak amplitudes of N2pc and SPCN were found in time windows of 150–300 and 350–600 ms, respectively.

Statistical analyses of onset latencies of N2 to D1, P300 to T1, and N2pc and SPCN to T2 were based on jackknife procedures (Brisson & Jolicaeur, 2007; Kiesel, Miller, Jolicaeur, & Brisson, 2008; Miller, Patterson, & Ulrich, 1998; Ulrich & Miller, 2001). The onsets and peaks were identified based on the time course of activity averaged across participants (i.e., $N-1$ grand averages), and the values were submitted to a conventional analysis of variance (ANOVA) or t test, with the F or t values adjusted according to $F_{\text{adjusted}} = F/(N-1)^2$, or $t_{\text{adjusted}} = t/(N-1)$ (for a general proof of this adjustment, see Ulrich & Miller, 2001). Specifically, to determine the onset latency of each ERP component in this study, the jackknife approach was combined with a relative criterion technique, according to which an ERP onset was defined as the time point at which the amplitude reached 50% of the peak amplitude (Kiesel et al., 2008).

2.2. Results

2.2.1. Behavioral results

T1 accuracy was on average 97% across the three experimental conditions. No significant differences were found between conditions, indicating that T1 report was not influenced by D1 condition or T2 location. Table 1 summarizes the main statistical results for the behavioral and ERP data.

Trials with an incorrectly reported T1 were excluded from the analysis of T2 accuracy. ANOVA based on this conditional accuracy (i.e., T2|T1), with D1 condition (D1 absent, D1 at lag −1, and D1 at lag −3) and T2 location (left, right) as two within-participant factors, showed no significant main effect of T2 location, $F < 1$, but a significant main effect of D1 condition, $F(2, 30) = 30.37$, $p < 0.001$. T2|T1 accuracy was the highest for D1 absent (79.7%), the lowest for D1 at lag −1 (70.7%) and intermediate for D1 at lag −3 (73.8%). Bonferroni-corrected pairwise comparisons showed that while the differences between D1 absent and the other two conditions were significant ($ps < 0.05$), the difference between D1 at lag −1 and −3

Table 1
Mean values for D1 conditions in Experiment 1. The significance of *F* value refers to the main effect in ANOVA.

	D1 absent	D1 at lag −1	D1 at lag −3	Significance of *F* value
T1 accuracy (%)	96.9	97.7	96.7	$p > 0.1$
T2|T1 accuracy (%)	79.7	70.7	73.8	$p < 0.001$
Intrusion rate (%)	–	14.6	8.3	$p < 0.001$
D1 N2 amplitude (μV)	–	−1.37	−1.13	$p > 0.1$
D1 N2 latency (ms)	–	278	278	$p > 0.1$
T1 P300 amplitude (μV)	7.82	7.87	8.03	$p > 0.1$
T1 P300 latency (ms)	254	253	254	$p > 0.1$
T2 N2pc amplitude (μV)	−1.27	−1.18	−1.19	$p > 0.1$
T2 N2pc onset latency (ms)	181	220	209	$p < 0.01$
T2 SPCN peak amplitude (μV)	−1.40	−1.47	−1.60	$p > 0.1$
T2 SPCN onset latency (ms)	399	416	416	$p = 0.055$

was only marginally significant, $p = 0.083$. No significant interaction between D1 condition and T2 location was found, $F < 1$. These results indicate that the presence of D1 impaired T2 performance and that the closer D1 was to T1, the stronger the impairment was.

The intrusion rates (i.e., the proportion of trials in which D1 was reported as T2, when D1 was present and T1 was correctly reported) were also analyzed using ANOVA with T2 location (left or right) and D1 condition (D1 at lag −1 or D1 at lag −3) as within-participant factors. Again, the main effect of T2 location was not significant, $F < 1$, whereas the main effect of D1 condition was significant, $F(1, 15) = 22.42$, $p < 0.001$, with the intrusion rate being higher for D1 at lag −1 (14.6%) than for D1 at lag −3 (8.3%). The interaction between T2 location and D1 condition was not significant, $F < 1$.

2.2.2. ERP responses to T2

Difference waveforms between the contralateral and ipsilateral presentation of T2, averaged across posterior electrode pairs are shown in Fig. 2 as a function of D1 manipulation. The difference wave for incorrectly reported T2s (i.e., trials in which T1, but not T2, was reported correctly) between contralateral and ipsilateral presentations is also presented in Fig. 2, collapsed over the three D1 conditions and excluding 4 (out of 16) participants who had <20 artifact-free error trials in one or more T2 location conditions involved in the comparison. For the remaining 12 participants, there were on average 55 artifact-free trials per participant for the left T2 and 53 for the right T2 in calculating ERP responses to the incorrectly reported T2. As shown in Fig. 2, the N2pc and the SPCN for the incorrectly reported T2 trials were severely suppressed in comparison to the correctly reported trials.

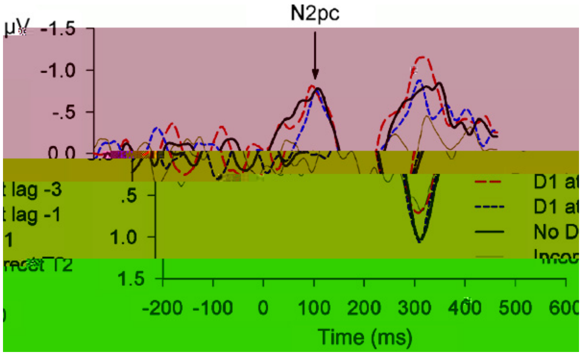

Fig. 2. Difference waveforms after subtracting the ipsilateral ERP response to T2 from the contralateral response to T2, averaged over P3/4, P5/6, P7/8, PO3/4, PO5/6, and PO7/8 in Experiment 1. The difference waveform for trials with incorrectly reported T2 is also included.

Onset latencies of the N2pc were analyzed with ANOVA with D1 condition and electrode pair as within-participant factors. The main effect of D1 condition was significant, $F(2, 30) = 6.70$, $p < 0.01$ (see

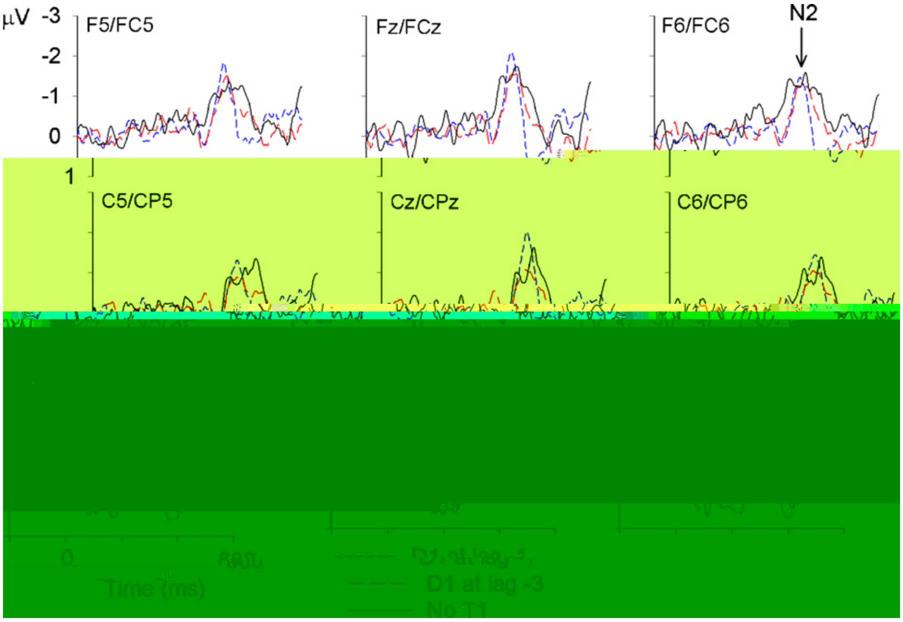

Fig. 3. Difference waveforms of ERP responses to D1 on exemplar electrode pairs in Experiment 1. ERP responses to the letter distractor at lags −1 or −3 in D1 absent trials served as the baseline and were subtracted from ERP responses to D1 in D1 present trials at the corresponding position. The waveform of “No T1” was extracted from the difference between filler trials with D1 present and D1 absent.

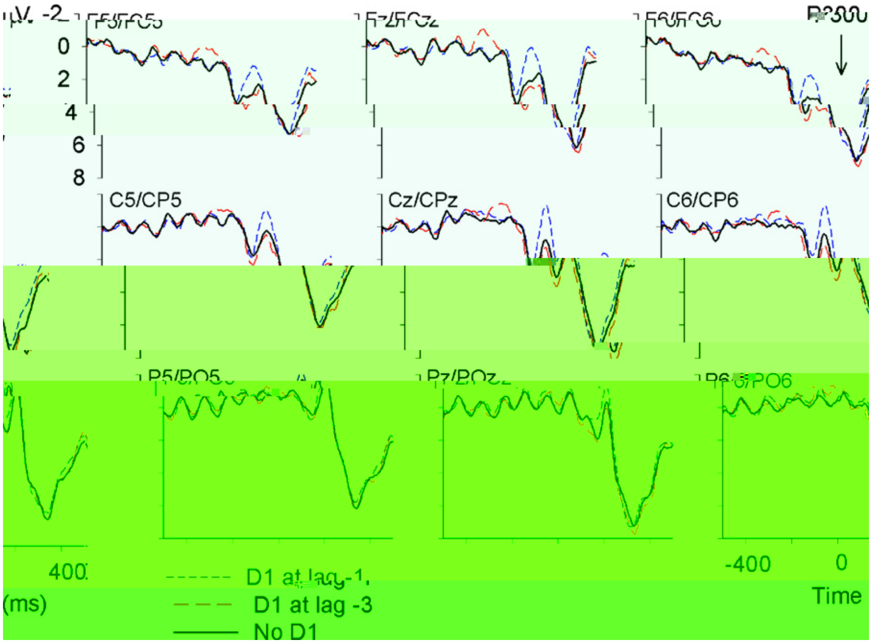

Fig. 4. ERP responses to T1 on exemplar electrode pairs in Experiment 1.

Table 1). Bonferroni-corrected t tests revealed a significant difference between D1 absent and D1 at lag −1, $t(15) = 3.57$, $p < 0.05$, and between D1 absent and D1 at lag −3, $t(15) = 3.74$, $p < 0.05$, indicating that the presence of D1 delayed the onset of N2pc to T2.

For the SPCN onset latencies, the main effect of D1 condition was marginally significant, $F(2, 30) = 3.19$, $p = 0.055$, with the onset latency being slightly delayed by D1 at either lag −1 or lag −3 (see Table 1). No significant effects were found in the analyses of N2pc or SPCN peak amplitudes (Fs < 1).

2.2.3. ERP responses to D1

Fig. 3 shows that, compared with letter distractors at the corresponding positions, the digit D1 at lag −1 and D1 at lag −3 evoked an N2 peaking at about 300 ms. While these N2 effects reached significance compared with zero, $ps < 0.001$, they did not differ from each other, $F < 1$. The jackknife-based analysis of the onset latency found no difference between the two D1 present conditions either, $F < 1$. These results suggest that D1 evoked negative ERP responses and that these responses did not differ significantly according to D1's temporal distance from T1.

2.2.4. ERPs to T1

Fig. 4 shows ERP responses to T1 in the three experimental conditions. Clearly, the uniquely colored T1 in all the three condition evoked the P300 component and the magnitude of this component did not differ between conditions (see the mean values collapsed across electrodes and p values in Table 1). These results suggest that the amount of attentional resources allocated to T1 was not evidently influenced by the D1 manipulation.

2.3. Discussion

Behavioral results showed that the presence of a digit D1 impaired T2 performance but had no effect upon T1 performance. Consistently, the N2pc and the SPCN to T2 were delayed by the presence of D1 but the P300 to T1 was not affected by the D1 manipulation.

The delay of the N2pc onset indicates that the allocation of attentional resources to the lateralized T2 was delayed by the presence of D1. This delay, which was found when both T1 and T2 were correctly reported, was likely to be due to a negative attentional set

Table 2

Mean values for D1 conditions in Experiment 2. The significance of F value refers to the main effect in ANOVA.

	D1 absent	Arabic D1	Chinese D1	Significance of F value
T1 accuracy (%)	97.6	98.2	95.7	$p < 0.05$
T2|T1 accuracy (%)	78.0	70.3	70.8	$p < 0.001$
Intrusion rate (%)	–	16.3	9.6	$p < 0.001$
D1 N2 amplitude (μV)	–	−2.6	−3.2	$p < 0.01$
D1 N2 latency (ms)	–	277	281	$p > 0.1$
T1 P300 amplitude (μV)	8.90	9.16	9.30	$p > 0.1$
T1 P300 latency (ms)	263	263	272	$p > 0.1$
T2 N2pc amplitude (μV)	−0.66	−0.49	−0.51	$p > 0.1$
T2 N2pc latency (ms)	209	216	231	$p < 0.05$
T2 SPCN peak amplitude (μV)	−0.85	−0.78	−0.88	$p > 0.1$
T2 SPCN latency (ms)	391	398	400	$p > 0.1$

tractor irrelevant to the task. Therefore, we suggest that a negative attentional set against the digit category is established upon the presence of D1 and continues to function over time, delaying the attentional allocation to T2.

3. Experiment 2

Experiment 2 was set up to examine whether the attentional set induced by D1 can be based on an abstract, conceptual level. To this end we used two types of D1, the Arabic digit (as Experiment 1) and the Chinese number character. While the first type of D1 shares both perceptual and semantic properties with a digit T2, the Chinese D1 is distinct from the digit T2 in terms of perceptual properties, but not in terms of conceptual category membership. The empirical questions were to what extent the Chinese D1 also elicits a negative attentional set and impairs T2 performance and whether the corresponding N2pc and SPCN effects would be observed in ERP responses to T2.

3.1. Method

3.1.1. Participants

Twenty-two right-handed Peking University students, not tested in Experiment 1, took part in this experiment. ERP data of two participants were excluded due to their low rate of artifact-free segments. The 20 remaining participants (13 females, mean age 23.2 years) had normal color vision and normal or corrected-to-normal vision.

3.1.2. Stimuli and procedures

The experiment had three critical conditions: D1 absent, the Arabic D1, and the Chinese D1. Both the Chinese D1 and the Arabic D1 appeared at lag −1 before T1. Each condition had 200 trials, with T2 appearing equally often on either the left or right side of fixation. Two hundred filler trials were used, with either an Arabic or a Chinese D1 embedded in the RSVP stream. Additionally 100 filler trials had only letters in the RSVP stream. The total 900 trials were divided into 20 test blocks. Twenty-four practice trials were presented prior to the formal experiment. The procedures of presenting stimuli, collecting, and analyzing behavioral and ERP data were the same as in Experiment 1.

3.2. Results

3.2.1. Behavioral results

A 3 (D1 condition) × 2 (T2 location) ANOVA on T1 accuracy revealed a significant main effect of D1 condition, $F(2, 38) = 7.14$, $p < 0.01$. The T1 accuracy in the Chinese D1 condition was significantly lower than that in the Arabic D1 or the D1 absent condition, $ps < 0.01$, whereas the latter two did not differ from each other, $p > 0.1$ (see Table 2). Thus, unlike an Arabic D1, when a Chinese number character appeared at the lag −1 position, it impaired T1 performance. Neither the main effect of T2 location nor the interaction between T2 location and D1 condition was significant, $Fs < 1$.

T2|T1 accuracies were analyzed in the same way. The main effect of D1 condition was significant, $F(2, 38) = 18.88$, $p < 0.001$, with T2 performance in the D1 absent condition being significantly better than in the D1 present conditions, $ps < 0.001$. The difference between the Chinese and the Arabic D1 conditions did not reach significance, $p > 0.1$. Neither the main effect of T2 location nor the interaction between D1 condition and T2 location was significant, $Fs < 1$.

The intrusion rates were analyzed with a 2 (D1 condition) × 2 (T2 location) ANOVA. The main effect of D1 condition was significant, $F(1, 19) = 20.86$, $p < 0.001$, with a higher intrusion rate for the Arabic D1 than for the Chinese D1 (see Table 2). Other effects were not significant, $Fs < 1$.

3.2.2. ERP responses to T2

Difference waveforms across 6 posterior electrode pairs are shown in Fig. 5. The N2pc latencies were analyzed with a 3 (D1 condition) × 6 (electrode pair) ANOVA. The main effect of D1 condition was significant, $F(2, 38) = 3.41$, $p < 0.05$, with a most delayed latency for the Chinese D1, the shortest for the D1 absent condition, and intermediate for the Arabic D1 (Table 2). Although the Bonferroni-corrected pairwise comparisons found only the difference between the D1 absent and the Chinese D1 conditions to be significant, $p < 0.05$, the trend of a linear increase of the latency over the D1 absent, the Arabic D1, and the Chinese D1 conditions was significant, $F(1, 19) = 9.0$, $p < 0.01$. The interaction between D1 condition and electrode pair was not significant, $F < 1$.

Analyses of the N2pc peak amplitude and the SPCN onset latency and peak amplitude found no significant main effects or interactions. On the other hand, ERP responses to T2 in trials in which T2 were incorrectly reported were clearly suppressed, as in Experiment 1 (see Fig. 5).

3.2.3. ERP responses to D1

Difference waveforms for ERP response to the Arabic and the Chinese D1, relative to the D1 absent (i.e., letter distractor) condition, are depicted in Fig. 6. Clearly, both types of D1 elicited an N2 with a frontocentral maximum. Statistical analyses showed that the

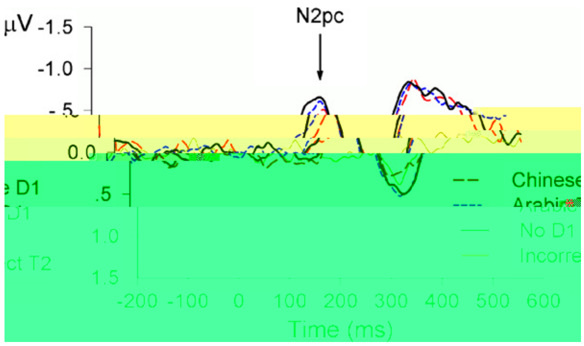

Fig. 5. Difference waveforms after subtracting the ipsilateral ERP response to T2 from the contralateral response to T2, averaged from P3/4, P5/6, P7/8, PO3/4, PO5/6, and PO7/8 in Experiment 2. The difference waveform for trials with incorrectly reported T2 is also included.

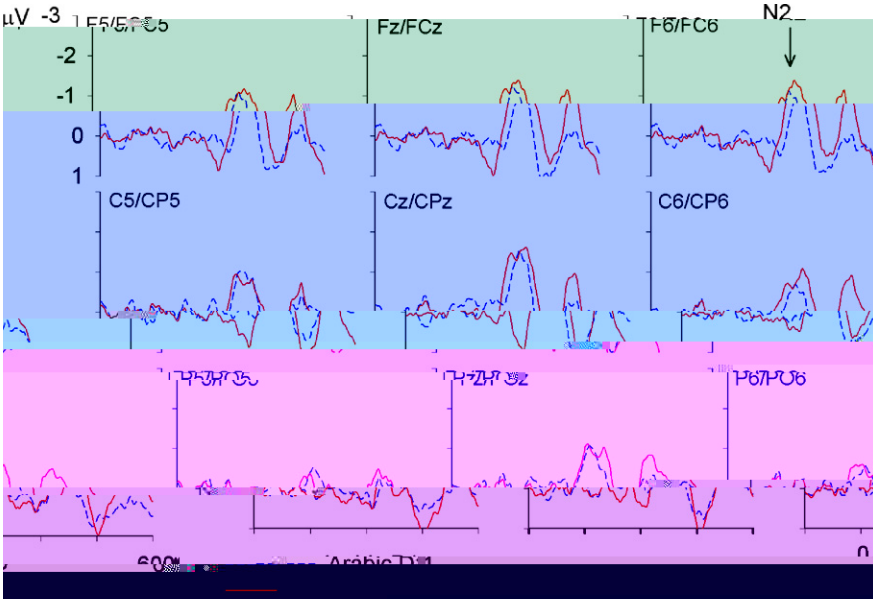

Fig. 6. Difference waveforms of the ERP responses to D1 on exemplar electrode pairs in Experiment 2. ERP responses to the letter distractor at lag −1 in D1 absent trials served as the baseline and were subtracted from ERP responses to D1 in D1 present trials.

peak amplitudes in both conditions were significantly larger than zero, $ps < 0.001$, suggesting that both the Arabic and the Chinese D1 evoked negative attention sets. Moreover, the N2 peak amplitude was more negative for the Chinese D1 (−3.2 μV; see Table 2) than for the Arabic D1 (−2.6 μV), $p < 0.01$. No effects were found in the analysis of the onset latency.

3.2.4. *ERP responses to T1*

As in Experiment 1, the P300 responses to T1 did not differ between D1 conditions (see Table 2).

3.3. *Discussion*

This experiment showed that both the Chinese D1 and the Arabic D1 impaired T2 performance, with the detrimental N2pc effect being slightly stronger for the Chinese D1 than for the Arabic D1, in accordance with the stronger N2 to the Chinese D1 than to the Arabic D1. Behaviorally, the Chinese D1 and the Arabic D1 impaired T2 performance to an equal extent, but the Arabic D1 induced more intrusion errors in T2 report than the Chinese D1. The Chinese D1 also impaired T1 performance, unlike the Arabic D1, although the P300 to T1 was not influenced by the D1 manipulation.

The impact of the Chinese D1 upon T1 performance was likely due to its ability in capturing attention. The Chinese number characters have perceptual properties distinct from those of the surrounding distractor letters and the native Chinese participants were sensitive to such properties. This saliency may increase the opportunity of the Chinese D1 to capture attention, making attention less easy to shift to the subsequent T1. The enlarged N2 to the Chinese D1 may partly reflect this attentional capture. Thus the Chinese D1 could influence T2 performance and the N2pc to T2 via two routes: an attentional capture-induced AB and the negative attentional set against the abstract, number category. This might explain why the N2pc to T2 was delayed more severely by the Chinese D1 than by the Arabic D1.

Although the N2pc latency to T2 showed a trend of linear increase over the D1 absent, the Arabic D1, and the Chinese D1 conditions, the difference between the Arabic D1 and the D1 absent conditions, unlike Experiment 1, did not reach statistical significance. Comparing Tables 1 and 2, we found that while the N2pc onset latency for the Arabic D1 at lag −1 was 220 ms in Experiment 1 and 216 ms in Experiment 2, thus showing no sign of an evident shift, the N2pc latency for the D1 absent condition was 181 ms in Experiment 1 and 209 ms in Experiment 2. Thus changing the composition of stimuli (i.e., having the Chinese number character as D1) somehow had particular influences upon the N2pc latency to T2 when D1 was not actually presented. Moreover, the rates of intrusion errors induced by the Arabic D1 at lag −1 did not differ between the two experiments, $t(34) < 1$, neither the T2|T1 accuracies, $t(34) < 1$. These results suggest that the reduced effect in Experiment 2 for the N2pc latency to T2 was likely due to the relative complexity of stimulus composition influencing brain responses to the baseline stimuli. Possibly, the type uncertainty of D1 in Experiment 2 might reshape the attentional set to the digit category to be more negative even in the baseline condition. Importantly for the present purpose, the Chinese D1, although distinct from the digit T2 in terms of perceptual features, impaired T2 performance and delayed N2pc to T2, suggesting that the negative attentional set from letters would impair the digit T2 performance and delay the N2pc latency to T2 even though D1 is not in the same semantic category as T2. A variant of this category-unspecific mechanism is that a feature-deviant D1 captures attention and the depletion of attentional resources by D1 somehow impairs T2 performance. As discussed previously, however, this attentional capture account is unlikely to stand as the digit D1 did not impair the report of T1, which was closer to D1 than T2, and as D1 evoked the frontocentral N2 rather than the P300 in the above two experiments.

Experiment 3 was conducted to rule out the category-unspecific, general negative attentional set account. To this end, we employed three types of D1: in addition to the Arabic D1 and the Chinese D1, a keyboard symbol D1, differing from T2 and letter distractors in terms of both perceptual features and category membership, was used. If it was the general negative attentional set, rather than a category-specific negative attentional set, that impaired T2 performance and delayed the N2pc latency to T2 in Experiments 1 and 2, then this symbol D1 should have similar negative impacts upon the digit T2. If, however, the negative attentional set was category-specific, the symbol D1 should have little effect on T2.

4.1. Method

4.1.1. Participants

Fifteen right-handed Peking University students (9 female, aged between 20 and 24 years old) took part in this experiment. They were not tested in Experiments 1 and 2 and were paid for their participation.

4.1.2. Stimuli and procedure

The stimuli and apparatus were essentially the same as in the previous experiments, with the following four exceptions. Firstly, each item in the RSVP was presented for 82 ms, rather than 100 ms, without inter-item interval. The second exception was that besides the Arabic and the Chinese D1, the symbol D1 could have one of the following forms: “?”, “#”, “/”, “%”, “>”, “<”, “*”, and “^” (cf. Chun, 1997). In addition, a conventional form of RSVP was used. That is, T2, without the accompanying letter distractor, appeared in the center of the screen, at the same location as D1, T1, and the letter distractors. The final difference was that a relatively full-range of T1–T2 TOAs was used. The TOA in this experiment had 3 levels (lags 1, 3, or 8) while the D1–T1 SOA was always lag −1. Thus the experiment was a 3 (TOA) × 4 (D1 type, including the D1 absent condition) within-participant factorial design. There were 32 trials for each combination of conditions. The experiment had 384 trials in total, divided over 8 testing blocks. Each participant received 24 practice trials before the formal experiment.

4.2. Results

The overall T1 accuracy was 80.1% (see Fig. 7A). ANOVA with TOA and D1 condition as two within-participant factors revealed a significant main effect of D1 condition, $F(3, 42) = 7.99$, $p < 0.001$. Bonferroni-corrected pairwise comparisons showed that T1 accuracy for D1 absent (84.5%) was significantly higher than that for the symbol D1 (78.3%) and the Chinese D1 (76.6%), $ps < 0.05$, but T1 accuracy for the Arabic D1 (81%) did not significantly differ from other conditions. These results indicated that the symbol D1 and the Chinese D1 have stronger abilities than the digit D1 in capturing attention and impairing T1 performance. The main effect of TOA was also significant, $F(2, 28) = 7.81$, $p < 0.01$, with T1 accuracy at lag 1 (82.9%) being significantly higher than that at lag 8 (78.6%), $p < 0.05$, and with T1 accuracy at lag 3 (78.9%) standing between them. The interaction between D1 manipulation and TOA was not significant, $F(6, 84) = 1.44$, $p > 0.1$.

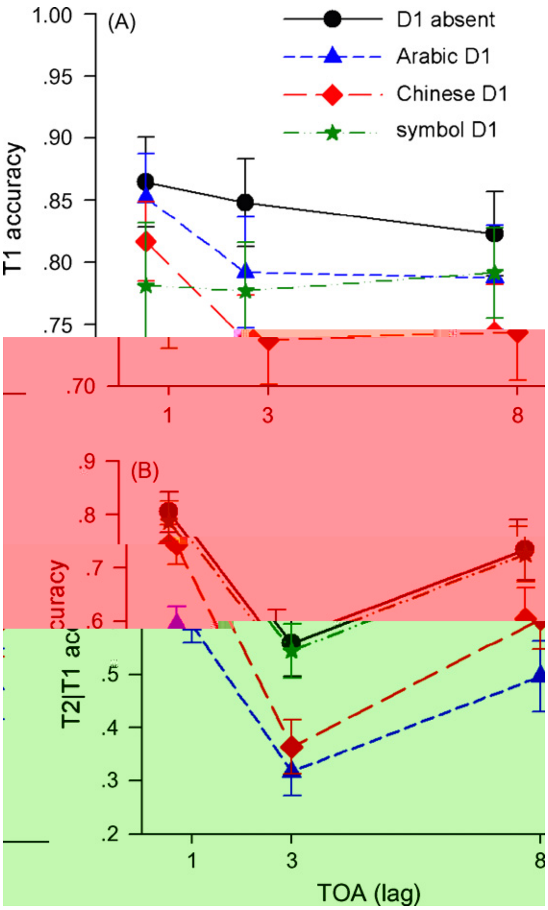

Fig. 7. Performance on T1 and T2 in Experiment 3. (A) Proportion of correct T1 identification. (B) T2 identification proportion for trials in which T1 was correctly reported (T2|T1).

T2 performance (see Fig. 7B) was analyzed in the same way, with a significant main effect of D1 condition on T2|T1 accuracy, $F(3, 42) = 37.97$, $p < 0.001$. While T2 performance did not differ between the symbol D1 and D1 absent conditions (68.6% and 70% respectively), T2|T1 performance in the Arabic D1 (46.9%) and the Chinese D1 (57.1%) conditions was significantly worse than that in the other two conditions, $ps < 0.01$. The difference between the Arabic D1 and the Chinese D1 conditions also reached significance, $p < 0.05$. These results indicate that both the Arabic and the Chinese D1 impaired T2 performance, but the symbol D1 did not. The main effect of TOA was significant, $F(2, 28) = 23.89$, $p < 0.001$, with the highest T2|T1 for lag 1 (73.3%), the lowest for lag 3 (44.6%), and intermediate for lag 8 (64%), indicating a substantial AB effect. The interaction between D1 condition and TOA was not significant, $F(6, 84) = 1.77$, $p > 0.1$.

Intrusion error rates were analyzed using a 2 (D1 type: the Arabic D1 vs. the Chinese D1) × 3 (TOA) ANOVA. The main effect of D1 type was significant, $F(1, 14) = 4.94$, $p < 0.05$, with a higher intrusion rate for the Arabic D1 (33.8%) than for the Chinese D1 (23.3%). The main effect of TOA was also significant, $F(2, 28) = 12.42$, $p < 0.001$, with the intrusion rate being significantly lower at lag 1 (20%) than at lag 3 (37.2%), $p < 0.05$, and with the intrusion rate at lag 8 (28.5%) standing between them. The interaction between D1 type and TOA was not significant, $F < 1$.

4.3. Discussion

Results showed that both the symbol and the Chinese D1 impaired T1 performance. More importantly, while the Arabic D1 and the Chinese D1 impaired T2 performance and induced intrusion errors, the symbol D1 had no impact upon T2 performance relative to the D1 absent baseline. Furthermore, the D1 effect on T2 performance did not interact with TOA, indicating that this effect is independent from the AB effect elicited by T1 and that the effect can last for a relative long time.

The absence of a symbol D1 effect on T2 performance allows us to rule out the possibility that the impairment of T2 performance (and the delay of the N2pc latency to T2) by the Arabic or the Chinese

D1 in current and the previous two experiments was simply due to a general, category-unspecific negative attentional set elicited by a perceptually deviant D1. The absence of a symbol D1 effect on T2 performance also rules out, again, the possibility that the impairment of T2 performance (and the delay of the N2pc latency to T2) by the Arabic or the Chinese D1 was simply due to attentional capture and depletion of attentional resources by D1. Although the symbol D1 did impair T1 performance, possibly through attentional capture, it had no effect on T2 performance.

This experiment also showed that the Arabic and the Chinese D1 impaired the report of T2 at both the short TOA (lag 3) and the long TOA (lag 8). Thus, although the TOA of lag 5 that was used in Experiments 1 and 2 may not be the position with the maximal AB effect and the maximal effect of negative attentional set upon T2 performance, given the constraints upon the ERP design, the TOA of lag 5 was sufficient to reveal the effect of a negative attentional set elicited by D1 on T2 performance and the N2pc latency to T2.

5. General discussion

This study investigates whether the negative attentional set elicited by a pre-T1 special distractor (D1) could influence the online target processing indexed by the report accuracy and the lateral ERPs in response to T2 in an RSVP stream. A D1 from the same conceptual category as the digit T2 was presented while the N2pc to T2 was measured. In Experiments 1 and 2, the N2pc was substantially suppressed in trials in which T2 was misreported relative to trials in which T2 was correctly identified. Moreover, the Arabic digit D1 at either lags −1 or −3 (Experiment 1) and the Arabic and the Chinese D1 at lag −1 (Experiment 2) evoked a frontocentral N2 component and delayed the onset of the N2pc to T2. In contrast, the P300 to T1 was not influenced by D1 manipulation in either experiment, although the accuracy of T1 report was somehow reduced by the Chinese D1. The behavioral data in the two experiments were consistent with the ERP results and showed that the Arabic or Chinese D1, belonging to the same semantic category as the digit T2, impaire T2 performance and cause intrusion errors in T2 report. Experiment 3 provided further behavioral evidence that while the Arabic or Chinese D1 impaired T2 performance, a keyboard symbol D1, which is perceptually deviant from distractor letters and T2 but does not share the category membership with T2, had no effect on T2 performance. Both the symbol D1 and the Chinese D1 impaired T1 performance, consistent with Experiment 2. These findings demonstrate that the online processing of the target in the RSVP stream can be impaired by a negative attentional set elicited by D1 sharing semantic properties with the target.

It is assumed that the processing system uses a negative attentional set to inhibit the processing of distractors in the RSVP stream (Maki & Padmanabhan, 1994; Olivers & Meeter, 2008; Olivers & Watson, 2006). An early study by Maki and Padmanabhan (1994) demonstrated that the AB effect was enlarged when items from the same category of T2 were inserted into the RSVP stream. Olivers and Watson (2006) also observed that T2 performance was impaired when T2 shared the same, task-irrelevant color as distractors preceding T1. Our previous behavioral study (Zhang et al., submitted for publication) extended these two studies by showing that the negative attentional set could be built upon abstract semantic categories and on a trial-by-trial basis. In the present study, we also observed that, for both the Arabic digit and the Chinese number character, D1 impaired performance on the digit T2 in the RSVP stream and induced intrusion errors in T2 report. However, these behavioral data do not provide unequivocal evidence pertaining to the question whether the impairment of T2 performance is due to competition between D1 and T2 at the retrieval stage during offline target report or whether it is due to an online inhibition of digit representations from a negative attentional set elicited by D1.

The present study provides electrophysiological evidence showing that the special distractor D1, which is from the same semantic category (i.e., in the same response set) as the subsequently presented T2 but which has to be ignored, not only evokes an inhibition-related frontocentral N2 upon its presentation, but also elicits a negative attentional set against the category to which D1 and T2 belong and inhibits representations of the members of this category. Since T2 had to overcome such inhibition, the N2pc response to T2 was thus delayed even in trials in which T2 was correctly reported. Given that the N2pc reflects online allocation of attentional resources to T2 (e.g., Eimer, 1996; Luck & Hillyard, 1994; Ruge et al., 2006), the delay of the onset latency of N2pc demonstrated clearly that the online processing of T2 can be inhibited by a negative attentional set established on a trial-by-trial basis.

Importantly, this negative attentional set is category-specific, due to D1 and T2 sharing the same semantic category and being task-relevant, rather than a general one, established by a processing mode against any items that are perceptually deviant from the letter stream. Experiment 3 demonstrated that a perceptually salient distractor, the symbol D1, had no effect upon the accuracy of T2 report even though it captured attention and affected T1 performance. The category-specificity of the negative attentional set elicited by D1 was further supported by the finding that the Chinese number character, which represents the same category as the digit T2, can also impair T2 performance and the N2pc response to T2 even though it has little perceptual similarity with the Arabic digit. The negative attentional set elicited by D1 is therefore based on an abstract semantic category although the perceptual similarity between D1 and T2 does play a role (Zhang et al., submitted for publication; see also Experiments 2 and 3 for the difference in the onset latency of the N2pc or the intrusion error rate). Thus we extended the finding of Olivers and Watson (2006) which demonstrated that T2 performance was impaired when T2 shared color with distractors preceding T1.

These findings have important implications for a current debate concerning the possible mechanisms underlying the AB. As we introduced in Section 1, the TLC hypothesis (Di Lollo et al., 2005) posits that in-depth processing of T1 occupies the central control system located in the prefrontal cortex and responsible for sending top-down control signals to the input filter. The distractors following T1 change the filter settings which are now at the mercy of the properties of the bottom-up input. Because the filter settings, which are initially configured by the top-down task demand, no longer match the specifications of T2, T2 processing is then impaired, resulting in the AB effect that is commonly observed in RSVP. Although the TLC hypothesis has already been under attack by the finding of intact endogenous cueing in an AB paradigm (Zhang, Shao, Nieuwenstein, & Zhou, 2008), the present study and our previous behavioral study (Zhang et al., submitted for publication) provides further evidence against this theory. The processing of T1 did not interrupt the negative attentional set elicited by D1 but rather strengthened it, as shown by the effect of temporal distance between D1 and T1 in Experiment 1. Moreover, the category-specific negative attentional set seems to be active for a relatively long period, reflected by the finding that a T2 presented more than 700 ms after D1 is still affected by it. Clearly, top-down control is not lost during the AB period and the TLC hypothesis cannot be a general theory about the AB mechanism.

The present findings are also consistent with other studies on attentional set in the spatial domain. Tipper and Driver (1988; see also Daza, Ortells, & Noguera, 2007) observed a negative priming effect at the abstract, semantic level when a visual distractor (a picture of a DOG) was presented on one trial and an auditory probe (the word CAT) in the subsequent trial. In an inattentional blindness task, Koivisto and Revonsuo (2007) found that an unexpected stimulus that belongs to the same semantic category as the attended stimulus but does not share its perceptual features was more likely to be detected than a semantically unrelated stimulus. Together with the present findings, we may argue for a general presence of abstract, category-based attentional sets in attentional selection over time or space.

To conclude, by measuring both behavioral performance and ERP responses to targets in the RSVP stream, we demonstrate that a special distractor D1 before T1 in the stream elicits a negative attentional set and impairs online T2 processing, delaying the N2pc response to T2. This negative attentional set is categorically defined at an abstract level and is categorically specific, such that it functions only when the inhibition-evoking D1 is in the same semantic category as the target.

Acknowledgements

This study was supported by grants from the Natural Science Foundation of China (60435010, 30770712), from Chinese Postdoctoral Science Foundation (20070420012, 200801027), and from Zhejiang Provincial Natural Science Foundation (Y207628). We thank the reviewers for their constructive comments and suggestions and Mr. Haiyang Zhang for helping us test the participants. Electronic mail concerning this study should be addressed to Dr. Xiaolin Zhou, xz104@pku.edu.cn.

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