Spatial congruence in working memory: an ERP study

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The Simon effect refers to the finding that reaction times are faster when stimulus and response locations are congruent than when they are not, even stimulus locations are task irrelevant. Zhang and Johnson reported a Simon-like spatial congruence effect in working memory. This study examined the neural mechanisms of this memory-based spatial congruence effect by recording event-related potentials to probe stimuli. Behavioral results showed a clear congruence effect. The P300 amplitudes were larger in the congruent condition than in the incongruent condition. The results suggest that the memory-based congruence effect and the classical Simon effect were mediated by similar neural mechanisms and support theories assigning response selection an essential role in spatial congruence effects. *NeuroReport* 15:2795–2799 © 2004 Lippincott Williams & Wilkins.

Key words: ERP; P300; Response selection; Simon effect; Spatial congruence effect; Working memory

INTRODUCTION

The Simon effect refers to the finding that in a task where stimulus location is irrelevant, reaction time is faster when stimulus and response locations are congruent than when they are not [1]. The response selection model proposes that this effect results from interference in response selection, where an automatically generated irrelevant spatial code interfers with the correct response code [2,3]. Alternatively, the perceptual-interference model suggests, that the interference occurs before response selection [4].

The Simon effect was studied as a perceptual phenomenon for several decades until researchers started, in the last few years, to expose its interaction with the memory system [5–9]. Recently, Zhang and Johnson [8] reported a Simon-like spatial congruence effect with a variant of the Sternberg working memory task. Participants first studied and held several items in memory over a brief delay interval and then responded to a probe item by indicating whether the probe was in the memory set. The critical feature was that the study items carried left or right spatial locations. This irrelevant source of spatial code was found to survive over a delay interval and affect performance to produce a Simon-like interference effect.

The fact that two very different experimental tasks, a perceptual classification task in the Simon effect literature and a working memory task in the Zhang and Johnson study, produce behaviorally similar spatial congruent effects, provides an avenue to contrast and compare the nature of the processes responsible for these effects. In this study, we recorded event-related brain potentials (ERPs) to examine whether the neural mechanism for the memory congruence effect is the same as that for the classical Simon effect. Previous ERP studies on the Simon effect have reported that P300 over parietal/central brain regions is modulated by the congruence between stimulus and response locations with a reduced peak amplitude and delayed onset in the incongruent condition relative to the congruent condition [10–12]. Thus it is of particular interest whether the memory congruence effect modulated P300 in a similar way.

The study design was the same as in Experiment 2 of Zhang and Johnson [8]. Participants were first presented with two letters in the left or right visual field (Fig. 1). They were to remember the identity of the letters across a delay interval and then decide whether or not a probe was among the memorized items.

MATERIALS AND METHODS

Participants: Twelve undergraduates (five females, mean age 22 years, age range 18–25 years) from Peking University participated with informed consent. All were right-handed with normal or corrected-to-normal vision. The study was approved by the Psychology Department Academic Committee.

Stimuli and procedure: The stimuli were in black against a gray background (116 cd/m^2) and presented on a monitor with a 120 cm viewing distance. A $0.19 \times 0.19^\circ$ fixation cross was visible at the screen center throughout the session. Two consonant letters (each $0.68 \times 0.68^\circ$ in size, center-to-center distance 0.68°) were displayed 3.77° to the left or right of the fixation for study. The probe letter was presented above the fixation (center-to-center distance 1.89°).

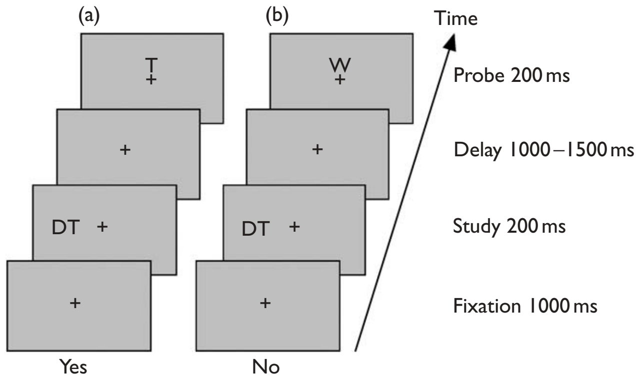

Fig. 1. Illustration of the experimental task. Participants remembered two consonant letters presented to the left or right of the fixation. They then decided whether a probe letter was in the memory set. The correct response was yes for (**a**) and no for (**b**).

Each trial began with fixation for 1000 ms. The study letters were then presented for 200 ms. Participants were asked to hold the letters in mind across a delay interval that varied randomly between 1000 and 1500 ms. The probe letter was then presented for 200 ms. Participants were asked to decide whether or not the probe letter was one of the study letters and respond by pressing a left or a right button in a button box. Participants held the box with two hands and placed their left (right) thumb on the left (right) button.

Each participant completed 10 blocks of 48 trials after 100 practice trials. The study letters were presented randomly and equally likely to the left or right of the fixation. The probe was present in the two study letters on half of the trials (yes trial) and absent in the other half (no trials). For yes trials, the probe letter was equally likely to be the first or second study letter. Half of the participants pressed the left button for yes and the right button for no. For the other half, the arrangement was reversed.

ERP recording and data analysis: The electroencephalogram (EEG) was recorded from 29 scalp electrodes located according to the International 10-20 system. Electrodes Oz, Pz, CPz, Cz, FCz, and Fz were arranged along the skull midline. Other electrodes were located symmetrically on the two sides of the skull. The right mastoid was used as reference. Eye blinks were monitored with electrodes located below the left eye. The horizontal electro-oculogram was recorded from electrodes placed 1.5 cm lateral to the left and right external canthi. The EEG was amplified with a half-amplitude band pass of 0.05–70 Hz and digitized online (sampling rate 250 Hz). The ERPs to the probe stimuli were averaged off-line with 1000 ms epochs starting 200 ms before probe onset. Trials contaminated by eye blinks, eye movements, amplifier clipping, or muscle potentials $<100\,\mu V$ (peak-to-peak amplitude) were excluded. Peak latencies were measured relative to stimulus onset.

Zhang and Johnson [8] found that the congruence effect interacted with response type, i.e., the congruence effect was positive for the yes trials (reaction time was faster in the congruent condition than in the incongruent condition) and negative for the no trials (reaction time was faster in the incongruent condition than in the congruent condition). We therefore classified each trial, in addition to being either a yes or a no trial, as either a congruent trial or an incongruent trial, depending on whether the side of the study letters, i.e., left or right to the fixation, was the same as or different from the side of the response key, i.e., the left or the right button. The resulting four types of trials, or conditions, i.e., yes-congruent, yes-incongruent, no-congruent, and no-incongruent, were equally represented and randomly intermixed within each block. ERPs were calculated separately for each of the four types of trials.

Mean reaction times and error rates were analyzed using a repeated measures ANOVA with response type (yes/no) and congruence (congruent/incongruent) as factors. The same ANOVA analysis was conducted on the mean ERP amplitudes during the 300–500 ms interval following probe onset, a time window chosen to focus on the P300 component. The P300 peak latency was automatically detected as the largest positive value in this window in the two parietal electrodes, P3 and P4.

RESULTS

Reaction time results showed a significant response type effect ($F(1,11)=129.5$, $p<0.001$), yes responses were faster than no responses (549 ms *vs* 592 ms). The congruence effect was not significant ($F<1$). There was a significant response type × congruence interaction ($F(1,11)=23.3$, $p<0.005$). The congruent condition was faster than the incongruent condition for the yes responses (537 ms *vs* 561 ms, $t(11)=10.9$, $p<0.01$) but slower for the no responses (601 ms *vs* 582 ms, $t(11)=16.4$, $p<0.005$). Error rates also showed a response type × congruence interaction ($F(1,11)=18.2$, $p<0.005$). For yes responses, subjects made fewer errors in the congruent condition than in the incongruent condition (4.9% *vs* 8.9%, $t(11)=11.6$, $p<0.01$). For no responses, the pattern was reversed (7.8% *vs* 6.0%, $t(11)=3.7$, $p=0.08$).

The grand average of ERPs associated with the probes, separated by condition, contained a positive wave (P1) followed by two negative components (N1 and N2; Fig. 2). The P300 component peaked between 300 ms and 500 ms. Focusing on the two parietal electrodes, P3 and P4, ANOVA analysis indicates that the mean ERP amplitudes between 300 and 500 ms showed a significant main effect for response type ($F(1,11)=47.2$, $p<0.001$) and for congruence ($F(1,11)=11.1$, $p<0.01$). There was no response type × congruence interaction ($F<1$).

Difference waves are shown in Fig. 3. P300 amplitude was larger (more positive) in the congruent condition (relative to the incongruent condition) regardless of response type and in the yes condition (relative to the no condition) regardless of congruence. Similar ANOVA analysis on P300 peak latency showed a marginally significant response type effect ($F(1,11)=4.19$, $p=0.07$; yes *vs* no: 420 ms *vs* 458 ms but no other effects ($F<1$)).

The voltage topographies of the difference waves for the congruence effect (i.e. congruent minus incongruent) are shown in Fig. 4, indicating parietal/central dominance.

DISCUSSION

The behavioral results replicated Zhang and Johnson [8] in finding a significant reaction time difference between the congruent and the incongruent conditions. The ERP results showed that congruence modulated P300 magnitude, with

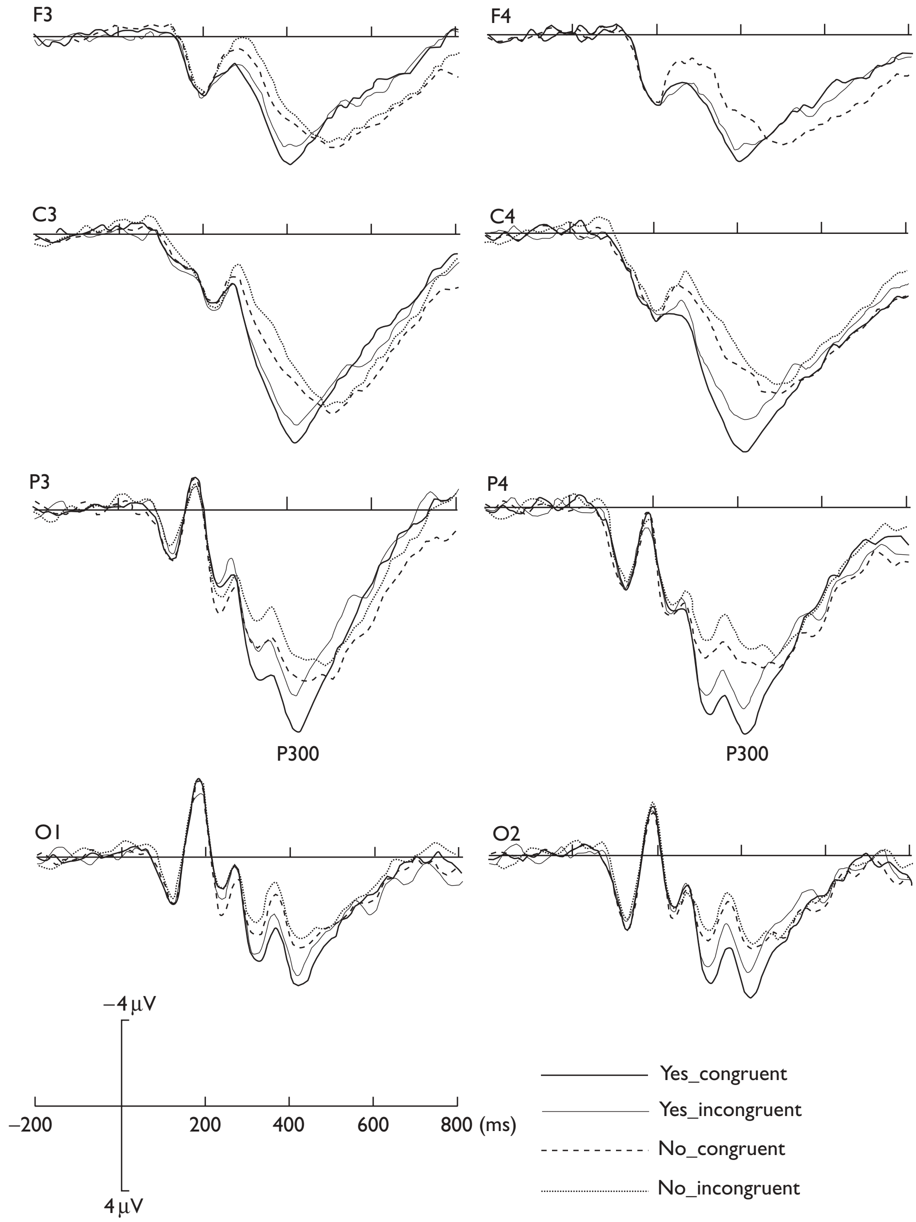

Fig. 2. Grand average of ERPs associated with response to the probes for each condition.

the congruent condition being more positive than the incongruent condition, consistent with the literature on the classical Simon effect [10–12]. This finding indicates that the memory-based congruence effect was associated with the same electrophysiological signature as was the Simon effect, suggesting that they may involve the same cognitive processes.

The Simon task and the Zhang and Johnson task are different in several aspects. One is a perception task and the other a memory task. Compared to the Simon effect, the memory congruence effect is more likely to reflect response selection processes. This is because neither study items nor probe items were intrinsically associated with the left or the right response, a factor central to the perceptual-interference account of the Simon effect [4].

The finding that the congruence effects from these two different tasks were associated with the same electrophysiological signature indicates that (1) response selection is an essential mechanism for the spatial congruence effect. Perceptual factors are unlikely to account for the effect alone; (2) the spatial congruence effect can be generalized to a wider context. It is not specific to perceptual processes but reflects some general feature of the human decision making process.

While previous ERP studies of the perceptual Simon effect report modulation of both P300 latency and magnitude by congruence [10–12], the current work found the congruency effect only on the amplitude. As the memory-based congruence effect is less subject to perceptual factors, such as stimulus evaluation often associated with P300 [13,14], this result suggests that P300 magnitude may be a better index for the congruence effect in the response selection stage. This is consistent with evidence that P300 latency reflects processing stages preceding P300 [15].

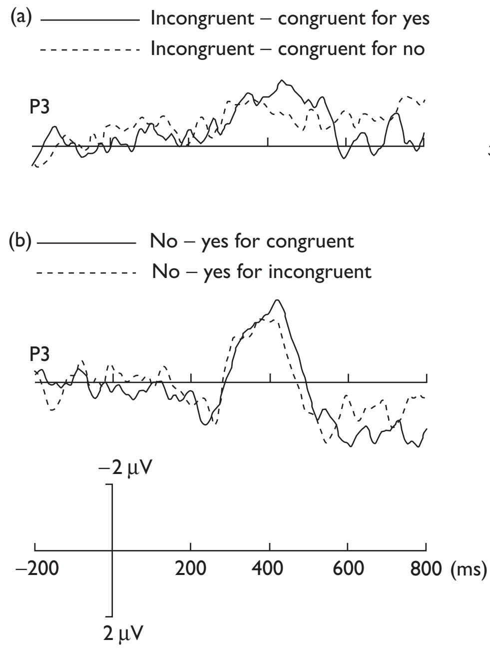

Fig. 3. Difference ERP waveforms over P3 and P4 electrodes, (**a**) incongruent minus congruent separated by response type; (**b**) no minus yes separated by congruence.

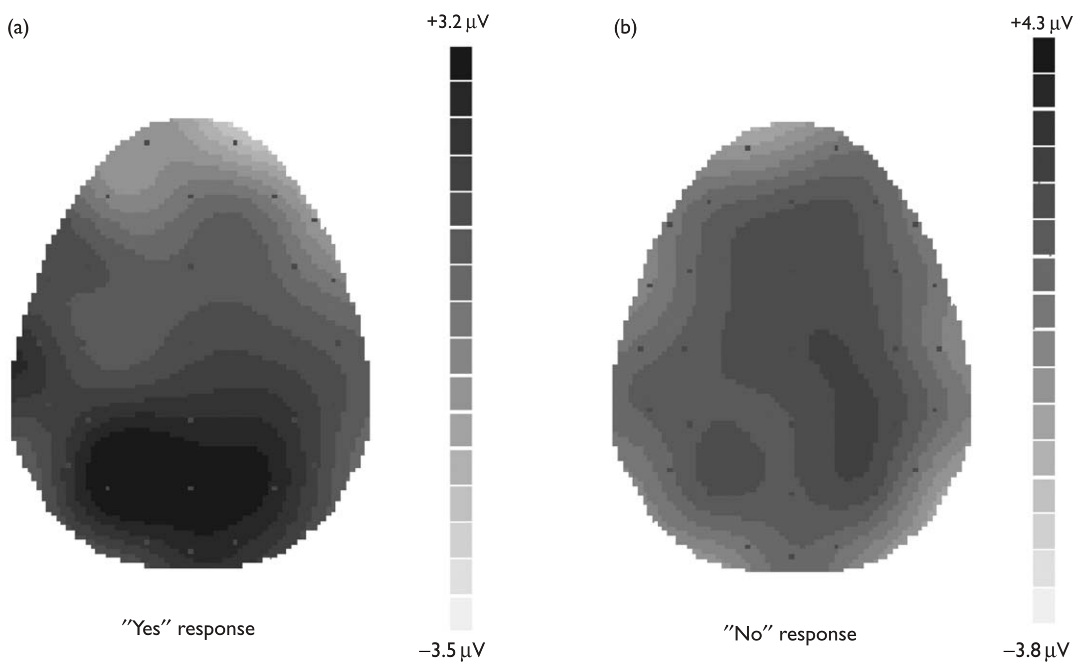

Fig. 4. Topography maps of ERPs showing scalp distribution of the difference waves for the congruence effect (congruent minus incongruent) in the P300 time window, (**a**) for yes trials during 380–480 ms and (**b**) for no trials during 452–552 ms. Time windows were centered at P300 peak.

The behavioral and ERP differences between yes and no responses reflect a response type effect [16,17], which is shown to be associated with prefrontal cortex activation [18,19].

Our behavioral results also replicated Zhang and Johnson [8] in finding a response type by congruence interaction, the congruence effect was positive for yes trials but negative for no trials. However, the ERP waveform showed no sign of such an interaction to mirror the reaction time data. Rather, the congruence factor modulated P300 in the same way for the yes trials and for the no trials. Given that response type and congruence were involved in choosing proper responses, this finding that P300 was sensitive to both factors but not to their interaction remains to be understood.

CONCLUSION

With the ERP technique, the present study identified similar neural mechanisms for the memory-based spatial congruence effect as that for the classical Simon effect. The results support theories proposing that response selection is an essential mechanism for the spatial congruence effect and further suggest that the effect is not specific to perceptual processes but may reflect general features of the human decision making processes.

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