Semantic processing is affected in inhibition of return: evidence from an event-related potentials study

Ming Zhang[a,b] and Yang Zhang[a]

[a]Department of Psychology and [b]Institute of Special Education, Northeast Normal University, Changchun, China

Correspondence and requests for reprints to Ming Zhang, PhD, Department of Psychology, Northeast Normal University, Changchun 130024, China
Tel: +86 431 5098 081; fax: +86 431 5098 081; e-mail: zhangm@nenu.edu.cn

Received 22 September 2006; accepted 18 October 2006

Inhibition of return refers to a slower responding to a target stimulus appearing at previously cued locations. We used the event-related potentials technique to investigate the effects of inhibition of return in semantic processing with the combination of a spatial cueing task and semantic N400 paradigm. The results showed that the N400 component, as an index of semantic processing, was suppressed when the target words were presented in the cued location relative to the uncued location. The results indicated that the semantic processing of the target word presented on the cued location is affected by inhibition of return. Moreover, our findings provided event-related potential evidence for the inhibition of attention theory of inhibition of return. *NeuroReport* 18:267–271 © 2007 Lippincott Williams & Wilkins.

Keywords: event-related potential, inhibition of return, N400, semantic processing

Introduction

It has been widely demonstrated in the visual attention literature that the sudden presentation of a spatially nonpredictive peripheral cue has a biphasic effect on the response to a subsequently occurring target. When the cue–target stimulus onset asynchrony was less than 300 ms, response latency for a target at a cued location was faster than for a target at an uncued location. In contrast, when the cue–target stimulus onset asynchrony was more than 300 ms, response latency for a target at a cued location was slower than for a target at an uncued location [1]. This latter phenomenon is known as inhibition of return (IOR), and is thought to provide an important search strategy for effective seeking in a complex visual environment [2].

Although IOR has received a great deal of research since Posner's seminal work, the nature of IOR is still the focus of debate. (i) The inhibition of attention theory assumed that IOR is due to attention being inhibited from returning to the previously attended locations [3,4]. (ii) The motor bias theory assumed that IOR arises from the reluctance to respond to a target at the previously cued location [5]. (iii) The inhibitory tagging theory proposed that IOR arises from disconnection between perceptual representations and their associated responses [6,7].

The event-related potentials (ERPs) technique has proved to be a useful tool for studying the ongoing processing of visual information within the brain. As yet, although several ERPs studies have investigated the neural correlates for IOR on sensory processing and/or motor processing [8–11], no report has investigated the neural correlates of IOR on other higher order cognitive processes, such as semantic processing. In the current study, we measure ERPs during a spatial cueing task in conjunction with the semantic N400 paradigm to determine whether the semantic processing is affected in IOR.

A vast number of prior ERPs studies about language processing have suggested that the N400 component as an index of semantic processing is highly sensitive to the degree of mismatch between words and previously established semantic context [12,13]. The N400 is a negative wave that peaks at about 400 ms after word onset and has a centroparietal topographical distribution [14]. Although N400 was originally found in sentence comprehension, it has also been found when sequentially presented in word pairs. The N400 is elicited when the second word has no semantic relationship with the first one [15]. In this present study, we used a modification of the experimental procedure of Vogel *et al.* [13] to isolate the N400 component for the target word. Specifically, we artificially established a semantic context at the beginning of each trial and compared trials on which the target word matched this context with trials on which the target word mismatched this context.

Examining how IOR might affect semantic processing not only demonstrates the generalizability of IOR but also provides some insight into the nature of IOR. According to the inhibition of attention theory, IOR is a truly attentional perceptual phenomenon. Thus, semantic processing, as indexed by N400, should be affected by IOR. Alternatively, according to the motor or inhibitory tagging theory, IOR reflects a bias to motor or a bias against connecting perceptual representations with their motor representations.

Thus, N400 should be equivalent for words presented in cued and uncued locations.

Method

Participants

Nineteen undergraduate students from Northeast Normal University were recruited in the experiment as paid volunteers. Three of them were excluded from the analyses because of excessive eye movement artifacts, which left 16 participants (10 women, six men) with a mean age of 22.3 ± 1.1 years. All participants, who gave written informed consent, were right-handed, had no history of neurological or psychiatric disorders, and had normal or corrected-to-normal vision. They had not participated in similar experiments during the past year. The study was approved by the Academic Committee of the Department of Psychology, Northeast Normal University, China.

Apparatus and procedure

Participants were seated in a dimly lit, sound attenuated room and sat about 80 cm from the computer screen and were instructed to maintain fixation on a centrally located fixation cross during the experimental blocks. Stimuli were presented on a 19 inch color Mitsubishi monitor. Screen refresh rate was set to 85 Hz. An IBM-compatible personal computer running E-prime software controlled stimulus presentation and data collection, and sent digital codes to the SCAN recorder (Neuroscan, El Paso, Texas, USA) to indicate the moment and the type of the simultaneously presented stimulus. Responses were made by pressing either the 'left' or the 'right' key on a Microsoft optical mouse.

The sequence of events on each trial is shown in Fig. 1. Each trial began with a white context word (horizontal and vertical visual angles of 1.6° and 0.8°, respectively, Chinese double-character word '医生', yi1 sheng1, which means doctor) presented on the center of the screen with dimly gray background for 1000 ms. After that a white central fixation cross (0.45° × 0.45°) was displayed together with two light gray peripheral boxes (one above and one below the fixation cross) for 906 ms. The boxes were 1.2° high and 2.4° wide, and were centered 2° above and below the fixation. A peripheral cue was then presented at one of the boxes for 153 ms and was then removed. The peripheral cue consisted of one of the boxes being filled with white and the outline of the box became thicker and brighter. After a 165-ms delay, a fixation cue (a white box 1° high and 1° wide) was presented at the fixation point for 153 ms and was then removed. After a variable delay of 223–495 ms, the white target word (horizontal and vertical visual angles of 1.6° and 0.8°, respectively, Chinese double-character word '护士', hu4 shi4, which means nurse) was presented and remained in view until the participant responded, or after 1300 ms had elapsed. The target word, either related or unrelated to the context word, was presented with equal probability within one of the two peripheral boxes. Half of the participants were instructed to press the 'left' key if the target word was semantically related to the context word and to press the 'right' key if the target word was not semantically related to the context word, whereas the other half of the participants were instructed to do the opposite. Both speed and accuracy were emphasized in the instructions. The intertrial interval was 800 ms.

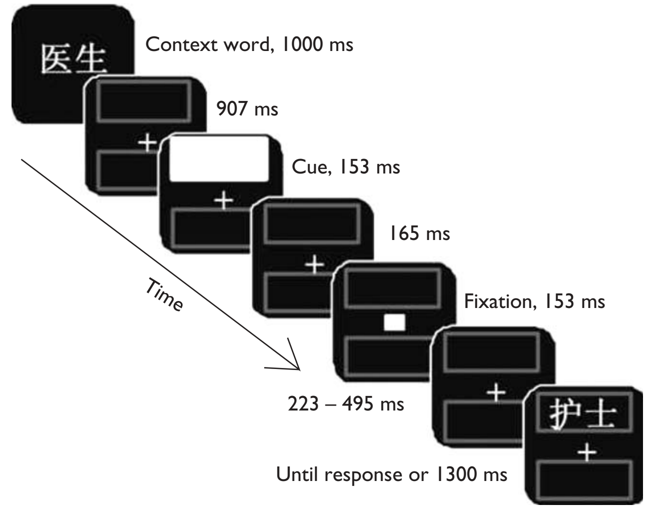

Fig. 1 Illustration of the stimuli and procedure used in the current study.

Design

The experiment had a two-factor (cueing × type of target word) repeated-measures design. The cueing variable had two levels: on cued trials the target and cue appeared at the same location, and on the uncued trials they appeared at opposite locations. The type of target words had two levels: on the related trials the target word was semantically related to the context word, and on the unrelated trials the target word was not semantically related to the context word.

The experiment consisted of 17 blocks of 40 trials, with the first one considered as practice. Within each block, the related and unrelated word appeared on half the trials, respectively. Each related word pair was randomly selected from a pool of 340 highly related Chinese double-character word pairs, and each unrelated word pair created by selected words at random from these pairs. Within each condition, there was the same number of cued and uncued trials. Thus, there were 160 trials for each experimental condition. All the words were two syllabled and the word frequency mean for the cued and uncued conditions was 55.0 and 54.1 per million, respectively. The total duration of the experimental task was approximately 90 min, with time for a break between the blocks.

Recording and data processing

Scalp potentials were continuously recorded using a SCAN system (Neuroscan) with a 32-channel Quick-cap. These electrodes were referenced to the right mastoid and subsequently rereferenced to an average of the activity at the left and right mastoids. For control of ocular movement, the electrooculogram (EOG) was recorded both vertically from above and below the left eye (vEOG) and horizontally from the outer canthi of both eyes. Electroencephalogram (EEG) and EOG were amplified and filtered by a Nuamps DC-amplifier (Neuroscan, 0–70 Hz band pass). EEG and EOG were sampled at 500 Hz and stored on another personal computer (IBM compatible) continuously. The impedance of all electrodes was kept below 5 kΩ.

Off-line, trials with errors and those with response times (RTs) outside 100–1300 ms were excluded from the analysis. A direct current correction was applied, and then ocular artifact was corrected with SCAN Edit (Neuroscan). After that a zero-phase digital band-pass filtering with 0.1–40 Hz as cut-off (slope=24 dB/octave) was applied. Trials on which EEG exceeded 50 μV were automatically rejected from the averaging process. Across participants, approximately 20% of trials were rejected from the averaging process (4.7, 5.1, 4.3 and 5.1% for uncued-unrelated, uncued-related, cued-unrelated and cued-related trials, respectively).

Data analysis

Behavioral analysis

Trials with RTs smaller than 100 ms (anticipations) or larger than 1300 ms (misses) were counted as errors. These types of error trials and trials with incorrect responses were excluded from the RT analysis. For each participant, mean RTs and error percentages were entered into repeated-measures analysis of variance with factors type of target word (semantically related to the context word vs. not semantically related to the context word) and cueing (cued vs. uncued).

Electroencephalogram analysis

ERPs were calculated time locked to the onset of the target word (for epochs from 200 ms before to 800 ms after the onset of the target word; the 200 ms before the target word served as baseline) separately for each condition. The N400 measures were taken in difference waveforms derived by subtraction of the ERPs to related words from the ERPs to unrelated words. The N400 component was measured from these difference waves as the mean amplitude 300–500 ms after stimulus. Electrodes F3, Fz, F4, C3, Cz, C4, P3, Pz and P4 were selected for parametrical analyses of N400 amplitude. The mean amplitudes were entered into repeated-measures analysis of variance with factors of cueing (cued vs. uncued) and electrode position (frontal, central and parietal). All statistically significant effects were corrected according to Greenhouse–Geisser when appropriate. In addition, paired-samples *t*-test was performed on the vEOG for the amplitude of N400 to determine whether the effects observed on N400 were possibly due to small eye movements in the direction of the cue.

Results

Behavioral performance

Latencies

The mean RTs for correct trials and error rates as a function of cueing and type of the word are shown in Fig. 2. As expected, participants were significantly faster in responding to target word on cued trials (689 ms) than on uncued trials (657 ms), $F(1,15)=18.8$, $P=0.001$, which is the typical IOR effect. A significant main effect also exists for the type of word, $F(1,15)=11.5$, $P=0.004$; responses to related words (653 ms) were faster than unrelated words (693 ms), which is the typical semantic priming effect (SP). The interaction between type of word and cueing was also significant, $F(1,15)=5.7$, $P=0.031$. Student's *t*-tests revealed that the SP effect was significantly larger at the cued location (45 ms) than that at the uncued location (37 ms).

Error rates

Only the main effect of cueing was significant, $F(1,15)=8.7$, $P=0.010$; responses on cued trials (9.7%) were less accurate than responses on uncued trials (8.4%). There was no effect

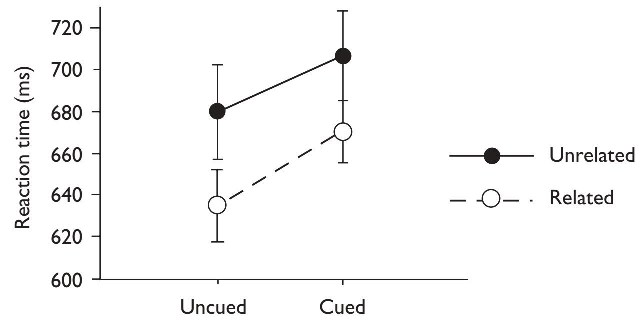

Fig. 2 Mean correct response times (± SEM) as a function of cueing and target word type.

of type of word, $F(1,15)=2.9$, $P=0.110$, nor a type of word × cueing interaction, $F<1$. Thus, there was no speed-accuracy trade-off, as the fewer errors also yielded faster RTs.

Event-related potentials

The difference waveforms by subtracting related words from unrelated words are plotted as a function of cueing in Fig. 2. The waveforms consisted of a negative-going potential that had the typical characteristics of the N400 component. Specifically, it was a negative going deflection, peaking at approximately 400 ms and with a centroparietal distribution [13].

The main effect of electrode position was significant, $F(1.5,23)=15.5$, $P=0.000$. Subsequent pair-wise comparisons indicated that the N400 was greatest at parietal locations (−1.94 μV), followed by central locations (−1.46 μV) and then frontal locations (−1.02 μV), which is consistent with the common effect of N400. The main effect of cueing was also significant, $F(1,15)=19.3$, $P=0.001$. N400 amplitude was significantly larger in the cued condition (−1.96 μV) than in the uncued condition (−0.98 μV). The interaction between cueing and electrode position, however, was not significant, $F(1.2,18)=1.5$, $P=0.243$, which indicated that the difference was reliable across the centroparietal area. Paired-samples *t*-tests on the vEOG revealed no significant difference between the cued and uncued conditions ($t<1$), indicating that the effect on N400 component was not caused by the small differences in gaze direction (Fig. 3).

Discussion

The main purpose of the study was to determine whether there is differential semantic processing for words presented in cued and uncued locations. In particular, we tested whether the semantic processing indexed by the N400 component to the target word is impaired in the cued location.

In line with previous behavioral studies of IOR and SP, a normal IOR and SP effect was observed. Specifically, (i) RTs to target words at the uncued locations were faster than RTs to target words at the cued locations. (ii) RTs were significantly shorter for semantically related words than for semantically unrelated words in both cued and uncued trials. (iii) The amount of semantic priming effect was larger for cued than for uncued trials. The most striking finding of the present study was that the N400 component elicited by

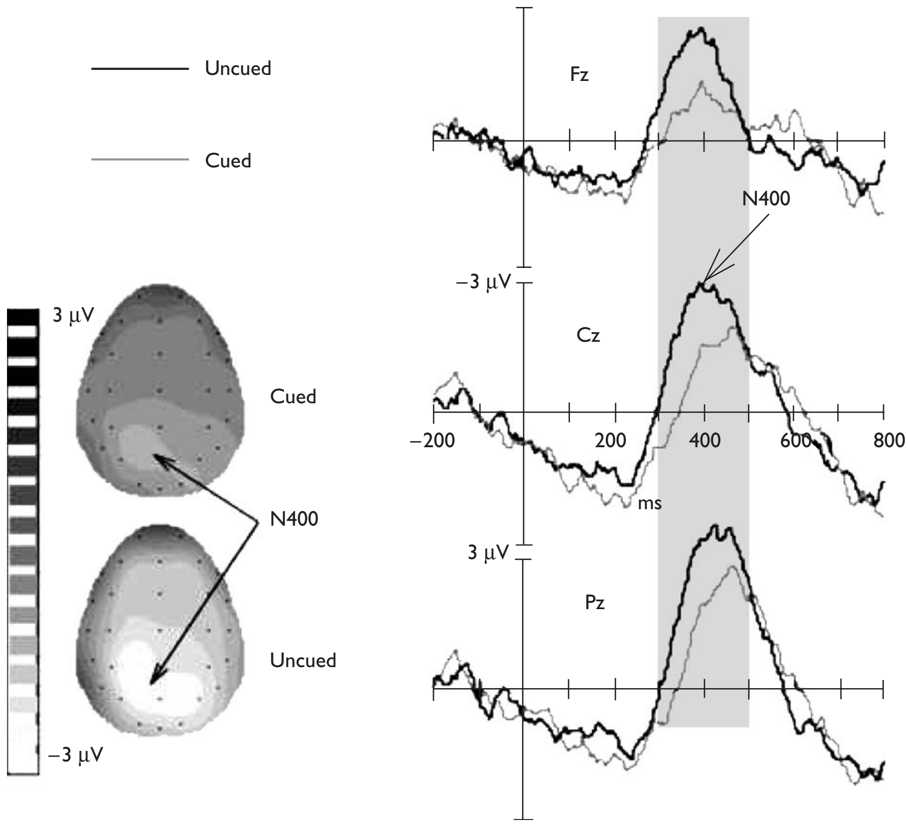

Fig. 3 Grand average event-related potential different waveforms for cued and uncued conditions. The different wave forms were formed by subtracting related words trials from unrelated words trials.

the target words was suppressed when the target words were presented in cued location.

A vast amount of ERP studies have suggested that the N400 component is a sensitive index of semantic processing. Specifically, its amplitude is related to either the intensity of lexical processing or the difficulty of retrieving conceptual representation associated with a word (see reviews in [16,17]). Thus, the suppression of the N400 component in cued trials strongly suggests that the semantic processing for the target word is affected by IOR. IOR therefore appears to arise from inhibition of attention rather than inhibition of motor processes or disconnecting perceptual representations with their motor representations.

An alternative explanation for the present results is that the difference of the N400 amplitude between cued and uncued trials reflects the small eye movements in the direction of the cue. No difference in the vEOG amplitude between the cued and uncued conditions, however, was found. Thus, it seems unlikely that such an explanation could contribute to the suppression of N400 on cued location in this study.

Consistent with our findings, several ERP studies have shown that IOR is associated with a suppression of sensory processes (smaller P1 on cued trials) and a delay of premotor processes (target-locked lateralized readiness potential) rather than a delay of motor processes (response-locked lateralized readiness potential) (see review in [11]). Although these ERP studies provide evidence for the inhibition of attention theory of IOR, it remains possible that the inhibition of other processes, especially the inhibition of motor processes, may contribute to IOR when oculomotor is used. Several studies have suggested that IOR is composed of attentional and motor components. The motor component of IOR is present when the response is oculomotor, and the attentional component of IOR is present when the response is manual [18,19]. In almost all ERP studies about IOR, the response was not saccadic eye movement. Rather, the eye movement was controlled to reduce eye movement artifacts. Further studies may rest on combining the ERPs and eye tracker technique to test this possibility.

Conclusion

In summary, the present findings suggest that IOR can modulate the degree to which target words are processed semantically. These findings also provide ERP evidence for the inhibition of attention explanation of IOR.

Acknowledgements

We thank Jie Sui and anonymous reviewers for comments on a previous version of this manuscript. We also thank YanQing Zhang for help with data acquisition.

References

1. Posner MI, Cohen Y. Components of visual orienting. In: Bouma H, Bouwhuis DG, editors. *Attention and performance X*. Hillsdale, New Jersey: Erlbaum; 1984. pp. 531–556.
2. Klein RM. Inhibition of return. *Trends Cogn Sci* 2000; **4**:138–147.
3. Reuter-Lorenz PA, Jha AP, Rosenquist JN. What is inhibited in inhibition of return? *J Exp Psychol Hum Percept Perform* 1996; **22**:367–378.

4. Klein RM, Dick B. Temporal dynamics of reflexive attention shifts: a dual-stream rapid serial visual presentation exploration. *Psychol Sci* 2002; **13**:176–179.
5. Taylor TL, Klein RM. On the causes and effects of inhibition of return. *Psychol Bull Rev* 1998; **5**:625–643.
6. Fuentes LJ, Vivas AB, Humphreys GW. Inhibitory tagging of stimulus properties in inhibition of return: effects in semantic priming and flanker interference. *Q J Exp Psychol A* 1999; **52**:149–164.
7. Vivas AB, Fuentes LJ. Stroop interference is affected in inhibition of return. *Psychol Bull Rev* 2001; **8**:315–323.
8. Prime DJ, Ward LM. Inhibition of return from stimulus to response. *Psychol Sci* 2004; **15**:272–276.
9. Wascher E, Tipper SP. Revealing effects of noninformative spatial cues: an EEG study of inhibition of return. *Psychophysiology* 2004; **41**:716–728.
10. Van der Lubbe RH, Vogel RO, Postma A. Different effects of exogenous cues in a visual detection and discrimination task: delayed attention withdrawal and/or speeded motor inhibition? *J Cogn Neurosci* 2005; **17**:1829–1840.
11. Prime DJ, Ward LM. Cortical expressions of inhibition of return. *Brain Res* 2006; **1072**:161–174.
12. Luck SJ, Vogel EK, Shapiro KL. Word meanings can be accessed but not reported during the attentional blink. *Nature* 1996; **383**:616–618.
13. Vogel EK, Luck SJ, Shapiro KL. Electrophysiological evidence for a postperceptual locus of suppression during the attentional blink. *J Exp Psychol Hum Percept Perform* 1998; **24**:1656–1674.
14. Ceballos NA, Houston RJ, Smith ND, Bauer LO, Taylor RE. N400 as an index of semantic expectancies: differential effects of alcohol and cocaine dependence. *Prog Neuropsychopharmacol Biol Psychiatry* 2005; **29**: 936–943.
15. Hinojosa JA, Martin-Loeches M, Rubia FJ. Event-related potentials and semantics: an overview and an integrative proposal. *Brain Lang* 2001; **78**:128–139.
16. Kotchoubey B. Event-related potentials, cognition, and behavior: a biological approach. *Neurosci Biobehav Rev* 2006; **30**:42–65.
17. Van Petten C, Luka BJ. Neural localization of semantic context effects in electromagnetic and hemodynamic studies. *Brain Lang* 2006; **97**: 279–293.
18. Hunt AR, Kingstone A. Inhibition of return: dissociating attentional and oculomotor components. *J Exp Psychol Hum Percept Perform* 2003; **29**: 1068–1074.
19. Sumner P, Nachev P, Vora N, Husain M, Kennard C. Distinct cortical and collicular mechanisms of inhibition of return revealed with S cone stimuli. *Curr Biol* 2004; **14**:2259–2263.