International Journal of Psychophysiology 88 (2013) 91–95

Contents lists available at SciVerse ScienceDirect

International Journal of Psychophysiology

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

Crowded words can be processed semantically: Evidence from an ERP study

Chunhua Peng [a,b], Yang Zhang [b], Youguo Chen [d,e], Ming Zhang [b,c,*]

[a] *Laboratory of Cognition and Mental Health, Chongqing University of Arts and Sciences, Chongqing 402160, China*
[b] *Department of Psychology, Northeast Normal University, Changchun 130024, China*
[c] *Academy of Psychology and Behavior, Tianjin Normal University, Tianjin 300074, China*
[d] *Key Laboratory of Cognition and Personality of Ministry of Education, Southwest University, Chongqing 400715, China*
[e] *School of Psychology, Southwest University, Chongqing 400715, China*

ARTICLE INFO

Article history:
Received 25 October 2012
Received in revised form 3 February 2013
Accepted 10 March 2013
Available online 17 March 2013

Keywords:
Crowding
Event-related potentials (ERPs)
N400
Semantic processing

ABSTRACT

The term "crowding" refers to impaired peripheral object identification due to the presence of nearby objects. In this study, event-related potentials (ERPs) were used to investigate semantic processing of crowded Chinese words by combining a crowding task with a semantic-priming paradigm. Results showed that the N400 component, an index of semantic processing, was elicited by both crowded and uncrowded words. These results suggest that words were processed semantically despite crowding, and that features of the crowded words were integrated correctly.

1. Introduction

Within the peripheral visual field, objects easily identified in isolation become more difficult to recognize when surrounded by other objects. This is called the "crowding effect" (Pelli and Tillman, 2008). Crowding effects can occur during various identification tasks, such as letter recognition (Pelli et al., 2004), orientation discrimination (Levi and Carney, 2009), and face recognition (Farzin et al., 2009). Moreover, the crowding effect also occurs in certain visuomotor tasks. For instance, grasping or reaching targets is more difficult within cluttered scenes (Bulakowski et al., 2009).

The crowding effect has been extensively studied for several decades, yet the precise mechanisms underlying the effect remain unclear. Crowding affects the discrimination but not the detection of a target (Livne and Sagi, 2007; Pelli et al., 2004). This suggests that crowding occurs at the stage of feature combination, following the stage of feature extraction (Levi, 2008). Some researchers suggest that crowding occurs at earlier levels of visual processing, implying a bottom-up account of crowding. This perspective implies that crowding occurs because features from targets and flankers are averaged compulsorily (Parkes et al., 2001) or combined into a jumbled percept (Pelli and Tillman, 2008; Levi, 2008). Several studies have substantiated the bottom-up account. For example, Yu et al. (2012) showed that word-crowding effects were invariant across different flanker configurations and proposed that word crowding arises from interactions between low-level letter features. However, He et al. (1996) showed that crowded targets could induce adaptation. He and colleagues proposed a top-down account to explain crowding, suggesting that while crowded targets could be perceived, the coarse attentional resolution in peripheral vision limits access of crowded targets to conscious awareness (He et al., 1996; Intriligator and Cavanagh, 2001). According to the top-down account, crowding occurs at later levels of visual processing, and crowded stimuli can be encoded and maintained in the visual system and induce nonconscious influences at higher processing levels (Kouider et al., 2011). Several studies have shown that crowded objects can influence human behavior through priming (Faivre and Kouider, 2011; Yeh et al., 2012) and biasing preference judgments of neutral stimuli (Kouider et al., 2011).

Although high-level processing in crowding is supported by some studies, most of these studies have mainly relied on measurements of behavioral output (e.g., accuracy or response time). However, behavioral results reflect the combined effects of several individual cognitive processes, and this makes it difficult to determine which stage of processing is influenced by a given experimental manipulation (Vogel et al., 1998). Event-related potential (ERP) recordings provide a continuous measure of processing and can be used to determine which stages are affected by a specific experimental manipulation (Luck, 2005). In the present study, we applied ERPs to examine high-level processes (e.g., semantic processing) involved in crowding.

Several ERP studies suggest that the N400 component is an index of semantic processing, and that in experiments where the second word in a sequentially presented word pair has no semantic relationship with the first word, the N400 component is elicited (Luck et al., 1996; Lau et al., 2008; Zhang and Zhang, 2007). For example, a large N400 would be elicited by the word "sock" in the word pair "Paper–

* Corresponding author at: Department of Psychology, Northeast Normal University, Changchun 130024, China. Tel./fax: +86 431 8509 8081.
E-mail address: psychzm@gmail.com (M. Zhang).

0167-8760/$ – see front matter
http://dx.doi.org/10.1016/j.ijpsycho.2013.03.002

Sock" compared to the pair "Shoe–Sock." If crowded words elicit a large N400 when semantically unrelated to the prime words, this can be taken as evidence that the crowded words are processed semantically.

2. Methods

2.1. Participants

Sixteen undergraduate students (four males) with normal or corrected-to-normal vision took part in the current study. Two participants were excluded from the analyses because of excessive artifacts. The remaining 14 participants were young (mean age $= 22.3 \pm 1.4$ years) native Chinese speakers. None of the participants suffered from any neurological or psychiatric disease, nor had they participated in similar experiments during the past year. All participants were unaware of the purposes of the study, and written informed consent was obtained from each participant prior to the tests.

2.2. Stimuli and apparatus

We employed two types of stimuli: Chinese pseudo-characters and Chinese characters. The former were used as flankers and consisted of four white single-body pseudo-characters made from stroke features by using TrueType software. None of the characters had any semantic meaning. The Chinese characters consisted of 240 white single-body characters, all of which were high-frequency characters (the frequency of their usage in Chinese corpus ranged from 0.08% to 0.92%) and contained 6–10 strokes.

In this study, 120 characters were used as primes and 120 characters as targets. Primes and targets were combined into 120 semantically related word pairs (for example, 风 means wind, 雨 means rain; 鞋 means shoe, and 袜 means sock) and 120 unrelated pairs (e.g., 鞋–雨, 风–袜). Semantically related word pairs were randomly selected from a pool of 255 highly related word pairs used in Lu's (2010) study. The unrelated word pairs were created by rearranging words at random from the related word pairs (Vogel et al., 1998). 20 participants who did not perform the ERP experiment were recruited to rate the semantic association strength of the related and unrelated pairs on a 7-point scale (1 = the semantic strength is very weak, 7 = the semantic strength is very strong). Results showed that the semantic association strength of the related pairs (Mean $\pm$ SE: 6.04 ± 0.14) was stronger than the strength of the unrelated pairs (1.56 ± 0.11), $t(19) = 25.64$, $p < .001$.

The horizontal and vertical visual angles of all the characters were $1° \times 1°$. Stimuli were presented on a 22-inch Iiyama MA203DT D color monitor with a background screen color of medium gray (RGB color coordinates: 128, 128, 128). Screen resolution was 1024×768 pixels at 85 Hz. A Dell-compatible personal computer running E-prime software controlled the stimulus presentation and data collection.

2.3. Study design and procedure

We implemented a two-factor (semantic relationship $\times$ crowding) within-subject design. The semantic relationship variable had two levels dependent on whether the target word was semantically related or unrelated to the priming word. The crowding variable also had two levels dependent on the spacing between target and flankers at either 1° (crowded trials) or 4° (uncrowded trials) with one target word and two flankers (flanker, target, flanker) simultaneously presented on the screen.

Participants were seated comfortably in a dimly lit, electromagnetic-shielded room at a distance of 80 cm from the computer screen and were instructed to view the screen. Fig. 1 illustrates the sequence of events. Each trial began with a white fixation dot (visual angle 0.4°), which was presented in the center of the screen for 1000 ms. Subsequently, a prime word was presented in the center of the screen for 1000 ms. After a randomized delay of 300–600 ms, a target word with two flankers, randomly selected from 4 pseudo-characters and centered at 6° eccentricity, was presented and remained in view until either the participant responded or a period of 1500 ms had elapsed. Targets and flankers were presented randomly in either the left or right visual field on the horizontal meridian. The same target word was presented in the same visual field for both the related and unrelated conditions. Participants were instructed to maintain fixation on the fixation point throughout the study and notice the targets out of the corner of their eyes. Participants were required to judge the semantic relationship between the prime and target words and make responses by pressing one of two mouse buttons with the thumb of either hand. Half of the participants were instructed to press the left mouse button if the target word was semantically related to the prime word and to press the right mouse button if the target was unrelated to the prime word, whereas the other half of the participants were instructed to do the opposite. The inter-trial interval was 500 ms. Response time and accuracy were recorded simultaneous to the EEG measures.

The study consisted of 480 trials—half relating to the crowded condition and half relating to the uncrowded condition. In each condition, 120 trials relating to the semantic related prime-target word pairs and 120 to unrelated word pairs. The same word pairs were used in both the crowded and uncrowded conditions, and ordering of word pairs was randomized for each participant. All 480 trials were divided into 12 blocks of which 2 blocks were allocated as the practice set and 10 blocks as the test set. Each block consisted of 40 trials equally divided between related and unrelated word pairs. The practice set consisted of 1 block with both the crowded and uncrowded conditions, respectively. Five blocks of each test set offered the task under the crowded condition and five under the uncrowded condition.

Because the same word pairs were used for both crowded and uncrowded trials, participants performed the task in the crowded condition before doing so in the uncrowded condition. This was done so that any practice effects could be minimized and the strength of crowding could be increased.

2.4. Electrophysiological recording and analysis

EEGs were recorded using a SCAN system (Neuroscan) with a 32-channel Quick-Cap. All of the electrodes were referenced online to the left mastoid, and re-referenced offline to the average of the left and right mastoid. The horizontal electrooculogram (hEOG) was acquired using a bipolar pair of electrodes positioned at the external ocular canthi, and the vertical electrooculogram (vEOG) was recorded from electrodes placed above and below the left eye. EEG and EOG were amplified and filtered by a SynAmps2 AC-amplifier (band pass 0.05–100 Hz, sample rate 500 Hz) and stored for off-line analysis. All impedances were maintained below 5 kΩ.

EEGs were processed offline using SCAN Edit (Neuroscan). EEGs were corrected for ocular artifacts with vEOG recordings, and then a zero-phase digital low-pass filtering with 30 Hz as cut-off (slope = 24 dB/octave) was applied. ERPs were time-locked to the onset of the target words with an average epoch of 1200 ms, including a 200 ms pre-stimulus baseline. Trials with response times (RTs) smaller than 100 ms (anticipations) or larger than 1500 ms (misses) and trials for which hEOG and EEG exceeded 50 μV were automatically rejected from the averaging process, 17.6 ± 9.7% of trials were rejected from the averaging process.[1]

[1] Previous studies found that 50 μV on the hEOG channel corresponds to an average deviation of about 3° toward the central fixation (Lins et al., 1993; Zhang and Luck, 2009). In the current study, the target words were centered at 6° eccentricity in the left or right visual field. To ensure that participants did not gaze foveally on the target, the trials on which the hEOG exceeded ± 50 μV were excluded from the data analysis. We further used the "peak detection" method to analyze the hEOG data in the −200–1000 ms time window of the rest of trials. The hEOG elicited by target words, which were presented at the left or right visual field in each condition, was measured separately. Results showed that the maximum amplitude value of the hEOG was less than 6.2 μV in each condition, corresponding to an average deviation of less than 0.4° toward the central fixation. Thus, we believe that participants did not gaze on the targets in the current study.

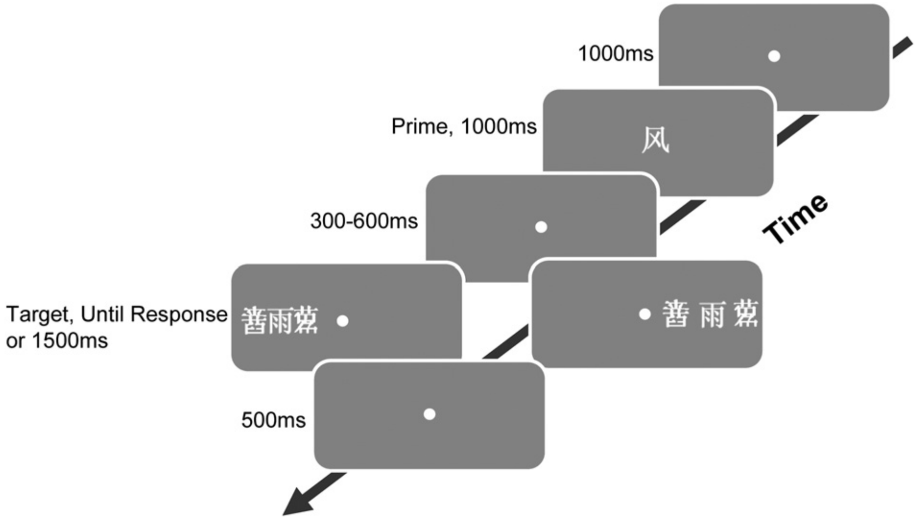

Fig. 1. Schematic illustration of the stimulus display sequence. The Chinese characters in the figure, 风 and 雨, mean "wind" and "rain," respectively.

3. Results

3.1. Behavioral performance

The analysis of behavioral data excluded the same trials as the analysis of the ERP data. Mean RTs and response accuracy for all 14 participants were entered into a two-way (semantic relationship × crowding) repeated measures ANOVA. The mean RTs and accuracy of each condition are shown in Fig. 2, separately.

For the RT data, the main effect of crowding was not significant, $F(1, 13) = 2.68$, $p = .126$, but the main effect of semantic relationship was significant, $F(1, 13) = 34.15$, $p < .001$, with related words eliciting faster responses (Mean ± SE: 754 ± 29 ms) than unrelated words (804 ± 34 ms). This suggests a typical priming effect. The interaction between semantic relationship and crowding was also significant, $F(1, 13) = 10.66$, $p < .001$, which indicated that priming effects were greater during the uncrowded ($RT_{unrelated} - RT_{related}$: 82 ± 16 ms) than the crowded trials (18 ± 9 ms).

For the accuracy data, there was a significant main effect of crowding, $F(1, 13) = 48.06$, $p < .001$, with the accuracy for crowded trials (55.9 ± 2.7%) being lower than that for the uncrowded trials (76.1 ± 3.9%), suggesting a typical crowding effect. The main effect of semantic relationship, $F(1, 13) = 2.79$, $p = .119$, and the semantic relationship × crowding interaction, $F(1, 13) = 0.14$, $p = .712$, was not significant, suggesting the absence of a significant priming effect in the accuracy data. This result may indicate that accuracy data are not sensitive to priming effects, or this result could be the result of a relatively small sample size ($N = 14$).

3.2. ERP components

ERPs for correct and incorrect trials were overlapped together for each condition (Vogel et al., 1998; Kang et al., 2011). The grand average ERPs for all 14 participants at Fz, Cz, and Pz electrodes are shown for crowded and uncrowded conditions in Fig. 3. The mean ERP voltages were statistically analyzed in the time window 300–500 ms after stimulus onset, which was selected to minimize contamination from the P3 component (Vogel et al., 1998; Kang et al., 2011). As in previous studies (Kutas and Hillyard, 1980; Kang et al., 2011), the key electrodes Fz, Cz, and Pz were selected for analysis. A three-way repeated measures ANOVA with semantic relationship (semantically related vs. unrelated), crowding (crowded vs. uncrowded) and electrode position (Fz, Cz, and Pz) factors was conducted on the mean voltages for all 14 participants. All statistically significant effects were corrected using the Greenhouse–Geisser method (Greenhouse and Geisser, 1959).

Results revealed significant main effects for crowding, $F(1, 13) = 9.72$, $p < .01$, semantic relationship, $F(1, 13) = 45.76$, $p < .001$, and electrode position, $F(2, 26) = 12.86$, $p < .01$, as well as significant interactions for crowding × semantic relationship, $F(1, 13) = 14.79$, $p < .01$, crowding × electrode position, $F(2, 26) = 5.93$, $p < .05$, and

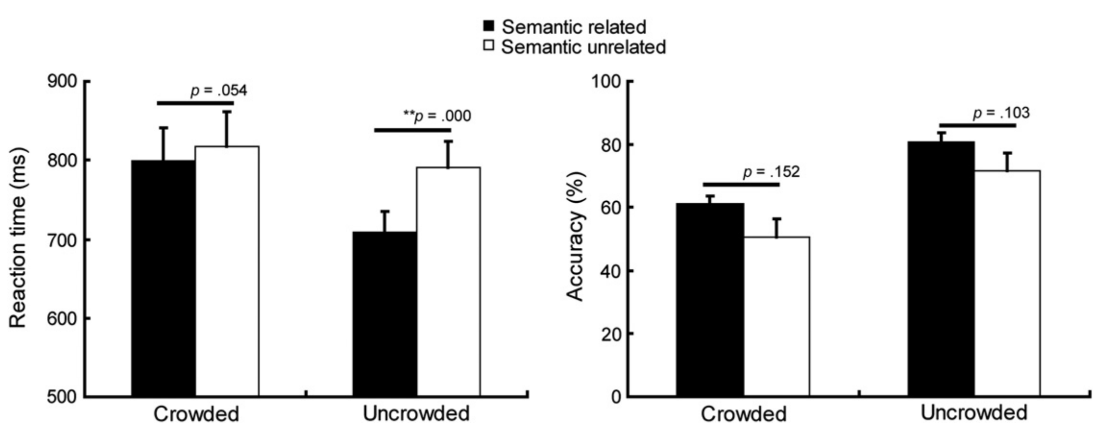

Fig. 2. Mean RTs and accuracy for the prime-target semantic-relatedness judgment for each condition. The error bars indicate standard errors.

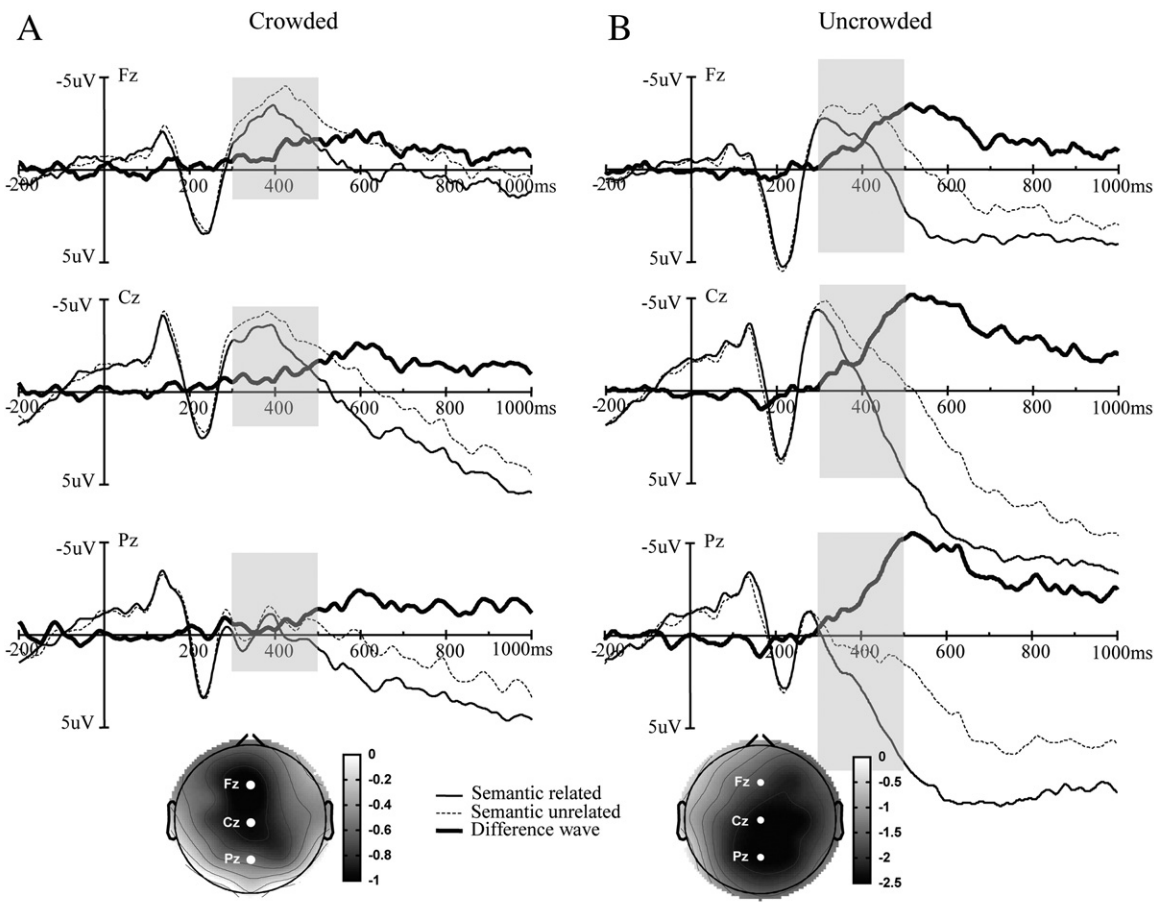

Fig. 3. The grand average ERPs for all 14 participants. (A) Top: ERPs for the semantically related and unrelated trials and the semantically unrelated minus related trials difference wave (N400) at electrodes Fz, Cz and Pz in the crowded condition. Bottom: topographical maps of the N400 at 300–500 ms in the crowded condition. (B) Top: ERPs for the semantically related and unrelated trials and the semantically unrelated minus related trials difference wave (N400) at electrodes Fz, Cz and Pz in the uncrowded condition. Bottom: topographical maps of the N400 at 300–500 ms in the uncrowded condition.

crowding × semantic relationship × electrode position, $F(2, 26) = 4.88$, $p < .05$. No other effects were significant, $ps > .05$. The ERP amplitude for the crowded condition (Mean ± SE: -2.13 ± 0.85 μV) was larger than for the uncrowded condition (-0.52 ± 0.56 μV). The amplitude for the unrelated condition (-2.12 ± 0.70 μV) was more negative than for the semantic related condition (-0.54 ± 0.67 μV). Furthermore, ERPs were largest over the frontal regions (Fz: -2.53 ± 0.72 μV). A simple effects analysis on the three-way interaction revealed significant semantic N400 effects (ERP difference between semantic unrelated and related trials) on each electrode position in both the crowded condition and uncrowded condition, $F(1, 13) = 5.63$ to 40.07, $ps < .05$. However, the mean difference between semantic unrelated and related trials was largest at Fz (1.06 ± 0.23 μV) and smallest at Pz (0.63 ± 0.27 μV) in the crowded condition, whereas the mean difference was largest at Pz (2.53 ± 0.27 μV) and smallest at Fz (1.80 ± 0.33 μV) in the uncrowded condition. This result was consistent with an earlier report that the N400 effect for masked words displays a more anterior distribution than for unmasked words (Coulson and Brang, 2010).

However, we found that the mean behavioral accuracy for 14 participants (Mean ± SE: 55.9 ± 2.7%) was above chance-level performance (50%), one-sample *t*-test $t(13) = 2.18$, $p = .048$. This suggests that in a small number of participants, the accuracy level was atypically high; therefore, the N400 component here may reflect the small number of trials in which participants accurately reported the targets. To address this possibility, we further analyzed the ERPs of eight participants with low discrimination performance in the crowded condition (49.5 ± 1.2%), one-sample *t*-test $t(7) = -0.39$, $p = .712$.

Supplementary Fig. 1 illustrates the grand average ERPs for the eight participants at the Fz, Cz, and Pz electrodes in the crowded and uncrowded conditions. A three-way repeated measures ANOVA (crowding × semantic relationship × electrode position) was conducted on the ERPs. The results revealed a significant main effect of semantic relationship, $F(1, 7) = 11.92$, $p = .011$, where the ERP amplitude of the semantic unrelated condition (-0.58 ± 0.72 μV) was more negative than that of related condition (0.76 ± 0.74 μV), which is a typical semantic N400 effect. No other main effects or interactions were significant, $ps > .05$. These results indicated that both crowded and uncrowded words could elicit a significant semantic N400 component even when a strict criterion is employed.

4. Discussion

The present study combined an ERP technique with a semantic-priming paradigm to investigate semantic processing of crowded words. As expected, we observed a crowding effect whereby the identification of crowded targets was impaired by neighboring flankers. However, the reaction time analysis revealed a priming effect for the crowded target. Moreover, ERP results indicated that a crowded target could elicit a significant semantic N400 component.

In a pilot study, we did not observe the semantic N400 component when crowded words were presented in the peripheral field for a short duration (350 ms). Yeh et al. (2012) also did not find a priming effect when the processing time was brief. This might be because the short time was insufficient for attentional deployment (Yeh et al.,

2012) or because lexical processing is slower in peripheral vision (Lee et al., 2003). However, in the present study, the crowded words were presented for a longer duration (the words remained on-screen until the participants responded or at the end of 1500 ms), and we found that these crowded words elicited an obvious N400 component. This provides, perhaps for the first time, electrophysiological evidence that crowded stimuli can be processed semantically.

A word must be perceived veridically before its meaning can be extracted (Vogel et al., 1998). Therefore, the semantic processing of a crowded word indicates that the features of crowded stimuli are integrated correctly. Here, crowding does not arise from excessive feature integration but from impaired access to integrated content (Faivre and Kouider, 2011). We should note that the semantic processing observed in this study might be caused by the partial processing of words (processing strokes or fragments of a word; Kouider and Dupoux, 2004). However, the Chinese words have small differences in strokes while having very disparate meanings (e.g., “耍” means “play,” and “要” means “demand”); thus, it is unlikely that semantic processing of the crowded targets in our study was due to partial word processing.

In addition, Block (2005) suggested that a criterion for reporting underestimates conscious content. According to this view, a small number of crowded words might actually be seen in the crowded condition, and semantic processing might be elicited by these words. However, we analyzed the ERPs of eight participants with low behavioral performance in the crowded condition and found that while performance was below chance, the N400 was still elicited by crowded words. Several scholars suggest that a chance level of performance is an index of unconscious processing (Kang et al., 2011; Lau and Passingham, 2007). Thus, the current results indicate that the semantic N400 could be elicited by unconscious crowded words. Of course, we cannot completely rule out the possibility that some crowded words were seen. Currently there is no effective way to solve this problem. Perhaps one way to deal with this issue is to evaluate the visibility of target stimuli (Sergent et al., 2005).

Furthermore, there is an unresolved debate as to whether nonconscious stimuli can be processed at a semantic level during visual processing. Some researchers have not observed the N400 when participants are unable to discriminate masked words within interocular suppression (Kang et al., 2011) and object substitution masking paradigms (Reiss and Hoffman, 2006). Whereas others have found that unidentified words can elicit a significant N400 during attentional-blink (Luck et al., 1996) and visual-masking paradigms (Coulson and Brang, 2010). Consistent with results using attentional-blink and visual-masking paradigms, our results observed that the unreportable words in the crowding paradigms elicited an obvious N400; therefore, our results provide a new avenue for further investigation toward identifying the processing level of nonconscious stimuli.

5. Conclusions

In summary, the N400 component, a sensitive electrophysiological index of semantic processing, was used to investigate semantic processing of crowded words in the present study. Our findings suggest that crowded words can be processed semantically, even if such processing is outside conscious awareness. These results provide electrophysiological evidence that the features of crowded words are integrated correctly.

Acknowledgments

This work was supported by the social science planning doctor projects in Chongqing Municipality (2012BS22), the Research Fund of Chongqing University of Arts and Sciences (R2012JY23), the MOE Project of Key Research Institute of Humanities and Social Sciences at Universities (2009JJDXLX004), and a grant for the National Natural Science Foundation of China (31200855).

Appendix A. Supplementary data

Supplementary data to this article can be found online at http://dx.doi.org/10.1016/j.ijpsycho.2013.03.002.

References

Block, N., 2005. Two neural correlates of consciousness. Trends in Cognitive Sciences 9, 46–52.
Bulakowski, P.F., Post, R.B., Whitney, D., 2009. Visuomotor crowding: the resolution of grasping in cluttered scenes. Frontiers in Behavioral Neuroscience 3, 1–7.
Coulson, S., Brang, D., 2010. Sentence context affects the brain response to masked words. Brain and Language 113, 149–155.
Faivre, N., Kouider, S., 2011. Multi-feature objects elicit nonconscious priming despite crowding. Journal of Vision 11, 1–10.
Farzin, F., Rivera, S.M., Whitney, D., 2009. Holistic crowding of Mooney faces. Journal of Vision 9, 11–15.
Greenhouse, S.W., Geisser, S., 1959. On methods in the analysis of profile data. Psychometrika 24, 95–112.
He, S., Cavanagh, P., Intriligator, J., 1996. Attentional resolution and the locus of visual awareness. Nature 383, 334–337.
Intriligator, J., Cavanagh, P., 2001. The spatial resolution of visual attention. Cognitive Psychology 43, 171–216.
Kang, M.S., Blake, R., Woodman, G.F., 2011. Semantic analysis does not occur in the absence of awareness induced by interocular suppression. Journal of Neuroscience 31, 13535–13545.
Kouider, S., Dupoux, E., 2004. Partial awareness creates the “illusion” of subliminal semantic priming. Psychological Science 15, 75–81.
Kouider, S., Berthet, V., Faivre, N., 2011. Preference is biased by crowded facial expressions. Psychological Science 22, 184–189.
Kutas, M., Hillyard, S.A., 1980. Reading senseless sentences: brain potentials reflect semantic incongruity. Science 207, 203–205.
Lau, H.C., Passingham, R.E., 2007. Unconscious activation of the cognitive control system in the human prefrontal cortex. Journal of Neuroscience 27, 5805–5811.
Lau, E.F., Phillips, C., Poeppel, D., 2008. A cortical network for semantics: (de)constructing the N400. Nature Reviews Neuroscience 9, 920–933.
Lee, H.W., Legge, G.E., Ortiz, A., 2003. Is word recognition different in central and peripheral vision? Vision Research 43, 2837–2846.
Levi, D.M., 2008. Crowding—an essential bottleneck for object recognition: a mini-review. Vision Research 48, 635–654.
Levi, D.M., Carney, T., 2009. Crowding in peripheral vision: why bigger is better. Current Biology 19, 1988–1993.
Lins, O.G., Picton, T.W., Berg, P., Scherg, M., 1993. Ocular artifacts in EEG and event-related potentials. I: Scalp topography. Brain Topography 6, 51–63.
Livne, T., Sagi, D., 2007. Configuration influence on crowding. Journal of Vision 7, 1–12.
Lu, Q., 2010. The neural mechanisms underlying N400 priming effects for different types of prime-target relationships and semantically primed Chinese characters (in Chinese). Unpublished master's thesis, Southwest University.
Luck, S.J., 2005. An Introduction to the Event-Related Potential Technique. MIT Press, Cambridge, MA.
Luck, S.J., Vogel, E.K., Shapiro, K.L., 1996. Word meanings can be accessed but not reported during the attentional blink. Nature 383, 616–618.
Parkes, L., Lund, J., Angelucci, A., Solomon, J.A., Morgan, M., 2001. Compulsory averaging of crowded orientation signals in human vision. Nature Neuroscience 4, 739–744.
Pelli, D.G., Tillman, K.A., 2008. The uncrowded window of object recognition. Nature Neuroscience 11, 1129–1135.
Pelli, D.G., Palomares, M., Majaj, N.J., 2004. Crowding is unlike ordinary masking: distinguishing feature integration from detection. Journal of Vision 12, 1136–1169.
Reiss, J.E., Hoffman, J.E., 2006. Object substitution masking interferes with semantic processing: evidence from event-related potentials. Psychological Science 17, 1015–1020.
Sergent, C., Baillet, S., Dehaene, S., 2005. Timing of the brain events underlying access to consciousness during the attentional blink. Nature Neuroscience 8, 1391–1400.
Vogel, E.K., Luck, S.J., Shapiro, K.L., 1998. Electrophysiological evidence for a postperceptual locus of suppression during the attentional blink. Journal of Experimental Psychology. Human Perception and Performance 24, 1656–1674.
Yeh, S.L., He, S., Cavanagh, P., 2012. Semantic priming from crowded words. Psychological Science 23, 608–616.
Yu, D.Y., Akau, M.M.U., Chung, S.T.L., 2012. The mechanism of word crowding. Vision Research 52, 61–69.
Zhang, W., Luck, S.J., 2009. Feature-based attention modulates feedforward visual processing. Nature Neuroscience 12, 24–25.
Zhang, M., Zhang, Y., 2007. Semantic processing is affected in inhibition of return: evidence from an event-related potentials study. Neuroreport 18, 267–271.