

Non-native Homonym Processing: an ERP Measurement

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Abstract. Using event-related brain potentials (ERPs), the present study examined non-native English speakers' brain activation of different meanings of English homonyms in inappropriate sentence contexts. We differentiated two types of homonyms: biased words *vs.* balanced words, where the former had a dominant and subordinate meaning respectively whereas the two meanings of the later type had a comparable usage frequency. High proficiency Chinese ESL participants were instructed to perform a lexical decision task in a 3 (word meaning types: balanced, biased dominant, biased subordinate) $\times$ 2 (Relatedness: related *vs.* unrelated) priming paradigm. Repeated measures ANOVA showed that related targets with the balanced or biased dominant meanings elicited a smaller N400 amplitude than unrelated ones but no such effect was found with biased subordinate meaning. Results suggested a dissociation of processing mechanisms for different word types. At 500ms stimulus-onset-asynchrony (SOA), both meanings of the balanced words were activated; whereas only the dominant meaning of the biased words could be activated in inappropriate sentence context.

Key words: ERPs; N400 amplitude; meaning activation; biased words; balanced words

1. Introduction

Homonyms are words with multiple unrelated meanings. For example, *fan* can denote *a ventilator* or *an enthusiastic supporter*. Homonyms, therefore, provide a unique opportunity for linguists to observe the lexical access to multiple meanings in speech perception and the possible effects of word meaning frequency and contextual information on lexical integration. While homonym processing has been investigated in native speakers of a language, the processing of homonyms by non-native speakers remains largely untouched [Elston-Guttler & Frederici, 2005]. This study examines Chinese ESL (English as a Second Language) learners' online lexical access of English homonyms.

Previous studies of non-native homonym processing with behavioral or ERP methods revealed contradicting results (table 1), which endorsed three different models for native language homonym processing: Multiple access, selective access, and ordered access. The Multiple (or exhaustive) access model [Lucas, 1987; Swinney, 1979] assumes that contextual information does *not* enter the early stage of homonym processing. In contrast, the Selective access model holds that sentential contexts do constrain the activation of contextually inappropriate meanings at an early stage in lexical access [Glucksberg, et al., 1986; Tabossi, 1988]. Furthermore, the Ordered access model suggests that initial activation is influenced by the *relative frequency* of the word meaning [Duffy et al, 1988].

Table 1. Contradicting results from previous non-native homonym processing studies.

Study	Participants	Paradigm	Findings
French-Mestre & Prince, 1997	French ESL High vs. low proficiency	Behavioral SOA 100vs.300	At both SOA, High level learners activate both meanings; low proficiency learners activate only dominant meaning. Multiple access and Selective access
Love et al, 2003	Multi-L1 ESL High proficiency	Behavioral SOA unclear	All meanings are activated. Multiple access.
Elston-Guttler, 2005	German ESL High proficiency	ERP SOA 200 vs.500	SOA 200ms: all meanings are activated. SOA 500ms: all meanings are activated and held. Multiple access.
Zhao & Dong, 2009	Chinese ESL High vs. low proficiency	Behavioral SOA 200vs.500	SOA200ms: high level: activate both meanings; low level: activate only dominant meaning. SOA500ms: high level: inappropriate subordinate meanings are suppressed; low level: activate both meanings. Ordered access.

Taken together, 500ms stimulus-onset-asynchrony (SOA) was the critical time where conflicting findings were observed. Thus, to further explore non-natives' online processing of homonyms, the present study set SOA at 500ms and differentiated between two kinds of homonyms, biased words and balanced words, where the former has a dominant and subordinate meaning respectively whereas the two meanings of the later type have comparable usage frequency. ERPs provide temporally exquisite brain measures that are powerful for getting aspects of cognition largely impenetrable with behavioral measures and for distinguishing among different processes and tracking their time courses even in the absence of awareness [Kutas & Federmeier, 2011]. One particular ERP component, the N400, has been found to be a robust negative component indexing semantic integration in language processing [Kutas & Hillyard, 1980]. In homonym processing studies, a reduced N400 component indicates eased lexical integration in both native [Van Petten & Kutas, 1987] and non-native language processing [Hagoort & Brown, 1994; Kotz & Elston-Guttler, 2004]. Thus, using ERPs, the present study measured Chinese ESL learners' online processing of homonyms with a lexical priming paradigm.

2. Methods

2.1 Design and material

With the target word SOA set at 500ms, the experiment adopted a 3 (word meaning types: balanced, biased dominant, biased subordinate) $\times$ 2 (Condition: related vs. unrelated) within-subject design. Participants were asked to judge whether the target word was a real word or a pseudo word under a lexical priming paradigm. All the critical words (prime words) were put in inappropriate sentence contexts in order to test whether the participants could activate the meaning represented by the target words (Table 2), which could be detected by the difference in N400 pattern between related vs. unrelated targets.

A preliminary test was carried out to select biased and balanced homonyms according to their respective meaning frequencies. This was defined by a norming study with another group of Chinese ESL students through a questionnaire, in which they indicated the familiarity of each meaning of a homonym (represented as meaning A and B) according to a Likert scale ranging from 1 to 5. We used the ratio between meaning A and B to define the word type (biased vs. balanced). Eighty balanced words (Ratio = 1.14; SD = 0.08) and 80 biased words were chosen (Ratio = 2.08; SD = 0.77). Independent samples t-test showed that the two types of words significantly differed in their meaning frequencies ($t = 8.482$, $p = 0.000$). Two counterbalanced test lists were created to ensure that each sentence or target would be read twice. Each participant only read one list which contains 120 related and another 120 unrelated targets. To make the real and pseudo words' ratio half to half, 240 pseudo target words were created in each list as fillers. All the stimuli were divided into 10 blocks with each block containing 48 trials.

Table 2. Example target words and critical homonyms with sentences.

meaning type	Condition	Example sentences	Target
Biased dominant	related	On her face he saw a strange air .	gas
	unrelated	On her face he saw a strange scarf.	gas
Biased subordinate	related	Let's go out for some fresh air .	expression
	unrelated	Let's go out for some fresh fruits.	expression
Balanced meaning A	related	We are shocked by his sudden appearance .	looks
	unrelated	We are shocked by his sudden laughter.	looks
Balanced meaning B	related	She never concerns about others' appearance .	arriving
	unrelated	She never concerns about others' idea.	arriving

2.2 Participants

Fourteen male senior college students (Mean = 20 years) from University of Electronic Science and Technology of China participated in the study. They had no experience of living in any English-speaking countries. All of them have studied English for at least 8 years and have passed the College English Test band-6 organized by the National Education Examinations of China, showing that they had a high proficiency in English.

2.3 Procedure and recording

Participants were seated in a comfortable chair and tested individually in a sound-proof room. Prior to the experiment, 20 practice items that were not used in the real test were prepared for participants. For each

trial, the participant first read an incomplete sentence (missing the last word) and pressed the space key when finished reading and ready to continue. The button-press would lead to the disappearance of the sentence and presentation of the last word, which lasted on screen for 500 ms before disappearing. The target word would then appear on the screen. Participants were instructed to press the yes-button if the target was a real word and the no-button if it was a pseudo word. The target would disappear immediately after the participants responded or remain on the screen for a maximum duration of 2000 ms before the next trial started. After finishing all the blocks, all participants were required to fill out a post-test in which they were asked to tick any unfamiliar words from all critical stimuli. The whole test lasted about 2 hours.

The EEG data were measured using the Electrical Geodesics (EGI) system with dense array geodesic sensor nets with 128 Ag-AgCl electrodes connected according to the extended 10 – 20 system. The vertex served as the reference. Eye blinks were monitored with electrodes located below each eye and 1 cm lateral to external canthi. The EEG from each electrode was digitized online at 250 Hz and filtered with a band-pass of 0.3-40 Hz. All impedances were kept below 50 k Ω . Prior to averaging EEGs, artifact rejection was performed to discard epochs contaminated by eye blinks, amplifier clipping, or muscle potentials. The rejection criterion was a negative or positive value larger than 65 μ V. Trials with incorrect behavioral responses were excluded. Epochs 200 ms before the onset of the critical stimuli served as the baseline. Finally, recordings were re-referenced to ‘infinity’ reference provided by the reference electrode standardization technique off-line (Yao, 2001).

2.4 Data analyses

Statistical analyses over all the participants with 2 (Relatedness) x 3 (word meaning types) x 3 (Hemisphere) x 3 (Distribution) as repeated-measures were conducted to examine the amplitude difference of the N400 effect. As a centro-parietal maximum has been observed consistently for such an effect in response to words with sentence context in visual modality [Anderson & Holcomb, 1995; Van Petten & Kutas, 1990], each Region of Interest was defined by a critical electrode within centro-parietal scalp regions typically associated with the N400 component. Therefore, similar to previous studies [Kotz & Elston-Guttler, 2005], nine electrodes were selected as representative of nine different Regions of Interest: left anterior (F3), left central (C3), left posterior (P3), right anterior (F4), right central (C4), right posterior (P4), medial anterior (Fz), medial central (Cz) and medial posterior (Pz). The Greenhouse – Geisser correction was applied for effects with more than one degree of freedom.

3 Results

3.1 Behavioral results

Behavioral results showed significant main effects for relatedness ($F[1, 13] = 4.045, p=0.045$), types of word meaning ($F[1, 13] = 3.839, p=0.074$), and their interaction ($F[1, 13] = 7.383, p=0.007$). Step-down analyses showed that for balanced word meaning, reaction time (RT) for the unrelated targets was longer than related targets ($F[1, 13] = 4.881, p=0.031$); while for biased words, no difference in RT was found either for dominant ($F[1, 13] = 0.197, p=0.659$) or subordinate meaning ($F[1, 13] = 0.825, p=0.367$). No other significant effects for word meaning types emerged, except a shorter RT for balanced word meaning than for subordinate meaning ($p=0.031$).

3.2 ERP results

The modulation of the N400 for related versus unrelated targets was visible across all conditions. The N400 onset of the effect was slightly later than traditional one, so the N400 time window chosen for statistical analysis was 350–550 ms (Figure 1). ANOVA results showed a smaller N400 amplitude for related targets than unrelated targets ($F[1, 13] = 7.636, p=0.02$) and a marginally significant effect of types of word meaning ($F[2, 26] = 2.571, p=0.09$). The main effect of relatedness interacted with different types of word meaning ($F[2, 26] = 4.608, p=0.02$), but not with Hemisphere and Distribution.

Step-down by-frequency analyses revealed a dissociation of activation patterns for balanced words and biased words. For balanced words, related targets elicited a marginally smaller N400 amplitude than unrelated ones (Related: 0.55μ V, $SD=1.28$; Unrelated: -1.27μ V, $SD=1.03$; $F[1, 13]=10.195, p=0.007$). For biased words, the related targets with the biased dominant meaning elicited a smaller amplitude than unrelated ones (Related: -0.04μ V, $SD=1.27$; Unrelated: -2.22μ V, $SD=1.96$); $F[1, 13]=7.18, p=0.023$; whereas the related targets with the biased subordinate meaning elicited comparable N400 amplitudes with unrelated targets (Related: -1.23μ V, $SD=2.11$; unrelated: -0.61μ V, $SD=1.10$; $F[1, 13]=0.733, p=0.418$).

By relatedness analyses revealed that only the N400 amplitude elicited by related targets was significantly different ($F[2, 30] = 3.530, p = 0.042$). Post hoc analyses showed that targets for the biased subordinate meaning elicited larger N400 than that for both balanced ($p = 0.014$) and biased dominant meaning ($p = 0.091$); whereas no difference was found for the later two types ($p = 0.349$).

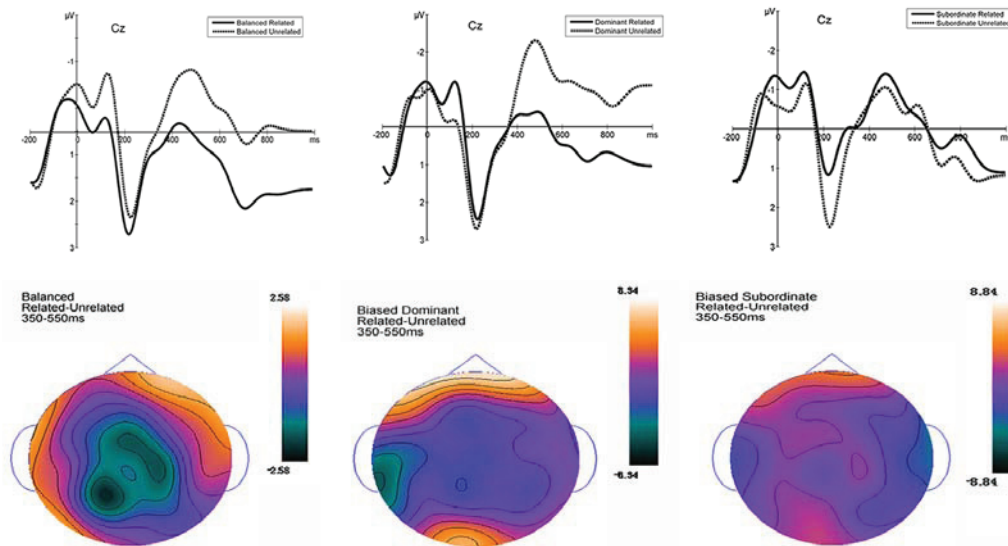


Figure 1. ERPs elicited by related vs. unrelated target words at Cz and topographical scalp distributions of N400 amplitude difference for different types of word meanings. Left: Balanced meaning; Middle: Biased dominant meaning; Right: Biased subordinate meaning.

4. Discussion

The present study examined Chinese ESL learners' online processing of balanced and biased English homonyms embedded in inappropriate sentences. The widely distributed N400 component observed at the time window of 350–550 ms in the present experiment supported previous ERP findings, which reported a consistent priming effect for related targets in homonym processing [Hagoort and Brown, 1994; Van Petten and Kutas, 1987]. The slightly later N400 latency replicated previous non-native homonym processing studies, which interpreted this finding as possibly reflecting non-native speakers' processing costs related to the integration of lexical meaning [Kotz and Elston-Guttler, 2005].

The degree of priming for related targets was indexed by N400 amplitude, which had been found to be sensitive to lexical (and subpart) frequency [Van Petten & Kutas, 1990] and expectancy or cloze probability of words in a context [Federmeier & Kutas, 1999; Federmeier & Laszlo, 2009]. In lexical priming paradigms, the amplitude of the N400 increased with the integration difficulties, and decreased with priming, which could facilitate integration [Anderson & Holcomb, 1995]. Thus, the smaller N400 amplitude elicited by the related target words for the balanced and biased dominant meaning suggested the ease of meaning integration resulted from priming. Meanwhile, the comparable N400 amplitudes elicited by the related and unrelated target words for the biased subordinate meaning indicated the absence of the priming effect. Together with the larger N400 effect elicited by the related targets for the biased subordinate meaning compared to balanced and biased dominant meaning, the present study suggested a dissociation of processing mechanism for the two types of words at 500ms SOA: for balanced words, context inappropriate meaning was activated; for biased words, context inappropriate dominant meaning was activated while context inappropriate subordinate meaning was not activated at all.

The dissociation of the ERP effects in the present study provided further evidence for non-native speakers' homonym processing and might reconcile previous contradicting findings. Elston-Guttler (2005) reported that advanced German ESL learners activate both meanings at 200ms SOA and still hold them at 500 ms SOA regardless of the context and suggested that non-native learners' homonym processing follow the multiple access model. Zhao & Dai (2009) found that high proficiency Chinese ESL learners activate both meanings at 200 ms SOA and suppressed the inappropriate subordinate meaning at 500ms SOA; while low proficiency learners activate the dominant meaning at 200ms SOA and the subordinate meaning at 500ms SOA, then suppress the subordinate meaning at 1100ms SOA in inappropriate sentence

context. So they concluded that non-natives' homonym processing follow the ordered access model. The dissociation of these findings might be a result of their failure to differentiate between the two types of homonyms. As the context inappropriate balanced word meaning and biased dominant word meaning were activated while the biased subordinate word meaning was not, their combined effect might lead to confusing result patterns.

The present findings also provided neuroinformational supports for an eye-tracking study by Rayner and Frazier (1989), which reported that "unbalanced words" behaved like non-ambiguous words in certain contexts while "balanced words" required more processing effort regardless of the context. The activation of the inappropriate meaning for the balanced words would compete with the appropriate meaning in the online homonym resolution process, which might consume more neural resources and thus require more processing effort. While for biased words, if the subordinate meaning was not activated, they would behave like non-ambiguous words.

To conclude, the present study suggested a dissociation of processing mechanisms for different word types in non-native speakers' homonym processing. At 500ms SOA, both meanings of the balanced words were activated regardless of context, endorsing the Multiple access model; for biased words, the dominant meaning was activated while the subordinate meaning was not activated in inappropriate sentence context, suggesting the Selective or Ordered access model. Future studies should differentiate between balanced words and biased words in homonym processing.

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