Hemispheric processing of Chinese polysemy in the disyllabic verb/ noun compounds: an event-related potential study

Chih-ying Huang
Institute of Linguistics
128, Sec. 2, Academia Road, Taipei, Taiwan, R.O.C
evelynhg@alumni.nccu.edu.tw

Chia-ying Lee
Institute of Linguistics
128, Sec. 2, Academia Road, Taipei, Taiwan, R.O.C
chiaying@gate.sinica.edu.tw

Abstract

Through the application of Chinese WordNet, the current study used the manipulation of visual field and the number of senses of the first character in Chinese disyllabic compounds to investigate the representation and the hemispheric processing of related senses in nouns and verbs. In the previous study, Huang et al. (2009) have found the ERP evidence to indicate single entry representation for Chinese polysemy in the left hemisphere; however, in the right hemisphere, they found sense inhibition which may be due to (1) the nature of hemispheric processing in dealing with semantic ambiguity or (2) the semantic activation from the separate-entry representation for senses. To clarify these possibilities, the study used the word class judgment task with the attempt to push subjects in a deeper level of lexical processing. The results revealed sense facilitation effect in the RH and suggested that in a deeper level, the RH had more possibility to observe the sense facilitation due to different efficiency of cerebral hemispheres.

1 Introduction

1.1 Homonymy vs. polysemy

Lexical ambiguity is very common in language. Linguistically, homonymy and polysemy are traditionally distinguished as two types of ambiguity. Early behavioral studies on semantic ambiguity obtained *ambiguity advantage* effects (e.g., Rubenstein et al., 1970; Jastrzembski, 1981, Millis & Button, 1989) in lexical decisions in which ambiguous words yielded faster reaction time than unambiguous words. However, the same results were not replicated in some other studies (e.g., Borowsky & Masson, 1996; Azuma & Van Orden, 1997). More recent psycholinguistic studies found that the so-called ambiguity advantage effects were in fact resulted from the activation of words having related *senses* rather than that of words having unrelated meanings (e.g., Rodd et al., 2002; Beretta et al., 2005; Pylkkänen et al., 2006). These studies were generally in agreement with the linguistic assumption in that homonymy and polysemy might be represented differently in the mental lexicon.

1.2 Hemispheric processing of semantic ambiguity

The issue of hemispheric processing in combination with lexical ambiguity have been widely studied (e.g., Burgess & Simpson, 1988; Beeman & Chiarello, 1998; Faust & Lavidor, 2003) and suggested that both cerebral hemispheres process word meanings in complementary ways. For example, Faust and Lavidor (2003) demonstrated that the LH benefited most from semantically congruent primes related to dominant meaning of ambiguous targets while the RH benefited most from semantically mixed primes. The overall pattern of priming was also suggestive of dissociation in the hemispheric meaning retrieval, with the LH engaging in *fine* semantic coding that focused on a single meaning interpretation, and the RH engaging in *coarser* semantic coding where multiple alternate meanings were activated. Alternatively, Federmei-

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er and Kutas (1999) offered electrophysiological data in a sentence comprehension task to present another explanation in hemispheric language processing. They suggested that while both hemispheres involved in lexical resolution, they played different roles with the LH being 'predictive', the RH being 'integrative', to complement each other.

Pylkkänen et al., (2006) were the first to focus on the investigation of how different but related senses were psychologically represented in the mental lexicon. Their MEG data suggested the single-entry representation for related senses in the LH whereas they showed the sense inhibition in the RH and interpreted it as a potential sense competition effect. In Chinese, Huang et al. (2009) demonstrated similar patterns in their ERP data in which there was sense facilitation in the LH and sense inhibition in the RH. Nevertheless, the question concerning the representation of related senses in the RH still left unresolved. Early studies on Chinese ambiguity such as Lin (1999) obtained ambiguity advantage but the calculation of 'senses' [1]included related and unrelated meanings and the effect was not reliable enough.

1.3 Ambiguity in Chinese disyllabic compounds

In Chinese words recognition process, the issue of lexical ambiguity involves the composition of constituent characters and how they contribute to the whole word reading. Chinese words differ from English in at least two aspects. First, about 80% of Chinese words are composed of two characters (Huang et al., 2006). Second, unlike the words in English, which every word is composed of letters corresponding to phonemes, Chinese words consist of characters corresponding to morphemes. In other words, each character in Chinese has its morpheme(s) when they are embedded in two-character compounds. Therefore, before we look into the lexical ambiguity of two-character words as lexical items, we should investigate the sense representation of its subcomponent, the representation of its single character within two-character compounds.

In the circumstance which every character in the disyllabic compounds may contribute to word recognition, there still exists disparity between the roles of the first and second character. In light of the studies on the neighborhood size effect, word recognition process will be influenced by the composition of letters or characters. In English, facilitative neighborhood size effects and inhibitory neighborhood size effects were robust findings in low frequency words (e.g. Andrews, 1989, 1992; Grainger and Jacobs, 1996). In the Chinese neighborhood size study (Huang et al., 2006) and eye movement study (Tsai et al., 2006), it was suggested that the neighborhood size of the first character constituent played a more important role in lexical processing than did neighborhood size of the second character constituent. Based on the assumption that the first character will play a key role in whole word reading, the study primarily manipulated the number of senses of the first character and attempted to reveal the hypotheses of sense representation in the context provided by the second character.

The question left in Huang et al. (2009) was that whether the sense inhibition in the RH was due to the nature of hemispheric processing in dealing with semantic ambiguity or the semantic activation from the separate-entry representation for senses. Considering the sense inhibition in the N400 of the ERP component, the pattern in their data was that words having many senses were more negative than those having few senses. That is, there existed competition when the first characters of the targets had many related senses. Nevertheless, based on the single entry assumption for related senses, we assumed sense facilitation for the representation of senses.

In Huang et al. (2009), they required subjects to make word/ non-word lexical decision, but subjects might make their judgments based on perceptual familiarity rather than the involvement of lexical access. Previous studies on probabilistic phonotactics (Vitevitch and Luce, 1998) or on Chinese semantic combinability (Cheng, 2006) have demonstrated opposing effects in early and late levels of word processing. In order to clarify the results in Huang et al. (2009), we designed the

[1] The definition of "sense" in Lin (1999) is different from the "sense advantage effect" demonstrated by Rodd et al. (2002). Lin argued that "meaning" in past research is used as a general term to refer to any kind of linguistic meaning. He claimed that, based upon Ahrens (1999) and Ahrens et al. (1998), it is better to use "sense" and "facets" as a measure index. Though the "number of senses" Lin used is a little different from the "number of meanings" used by Azuma and Van Orden (1997), it is regarded that Lin still did not solve the unreliable findings of ambiguity advantage effect.

word class judgment task to deepen the difficulty of the experimental procedure.

2 The experiment

By changing the depth of the task, the goal of the experiment was to find out if, under the assumption of single entry representation for senses, there was a chance to discover the sense facilitation in the RH. Suppose the representation of Chinese senses had single entry, words having more senses should be less negative than few senses in the N400 because of the benefits of semantic activation. On the contrary, if there were multiple entries for senses in the RH, words of more senses should be more negative than few senses and displayed semantic competition and inhibition.

2.1 Participants

38 college students (18 to28 years of age, mean age 22.39) took part in the experiment (male, right-handedness). Written consent was obtained from all participants. The study was approved by the Taiwan governmental ethics committee.

2.2 Materials

120 Chinese disyllabic compounds, counterbalanced with word class (noun/ verb), were divided into four subsets according to visual field (LVF/ RVF) and NOS of the first character (few/ many senses). Few-sense words were those whose first character senses were from 1 to 3 (mean 1.97) whereas many-sense words were those whose first character senses were over 6 (mean 11.38). Possible confounding factors such as word frequency, NS1, NS2 were controlled.

The number of senses in the current study was collected from the Chinese WordNet, a lexical corpus of Mandarin Chinese and established by Academia Sinica in Taiwan. The corpus attempts to build an up-to-date Chinese lexical network and provides complete information of Chinese word senses.

In Chinese, there exists controversy over the distinction of verbs and nouns. To avoid this problem, the resolutions included: (1) to label the word class according to the system established in Academia Sinica balanced corpus of modern Chinese and (2) to give pilot pretests to another group of people to exclude these possibly confused choices. These subjects were asked to use their language intuition to write down their word-class judgments in a paper sheet containing 120 targets.

Table1. Examples of the stimuli

No. of senses	Word class	RVF	LVF
Few	Noun	笑臉 ‘a smiling face’	髮夾 ‘a hair pin’
Few	Verb	猜謎 ‘to guess a riddle’	服藥 ‘to take medicine’
Many	Noun	頭獎 ‘first prize’	綠茶 ‘green tea’
Many	Verb	彎腰 ‘to stoop’	掉換 ‘to ex-change’

2.3 Procedure

Each trial began with a white cross presented centrally for 500 ms. Presentation of the target words appeared on the screen for 150 ms. The disyllabic compound targets were vertically arranged in the left or right visual hemifield with inner edge two degrees of visual angle from fixation. Presentation of numbers from 1 to 9 appeared pseudorandomly in the center of the screen in order to control participants' eyesight. At the end of each trial, a capital B was presented in the center to allow eye blinking for 1500 ms. Participants were asked not to blink their eyes until the appearance to the capital B to minimize the interference of eye movement.

Participants were instructed to judge whether the compound presented was a noun or a verb. For odd-number subjects, they were asked to press the response box with both of their index fingers when the targets were verbs and with both of their middle fingers when the targets were nouns. For even-number subjects, the instruction was the opposite. To control the central fixation of eyes, numbers from 1 to 9 also appeared pseudorandomly. Odd-number subjects should press the response box with both of their index fingers when number 6 to 9 was presented centrally on the screen and with both of their middle fingers when number 1 to 4 was on the screen. For even-number subjects, instruction reversed. Response time and event-related potentials data were both collected during the process.

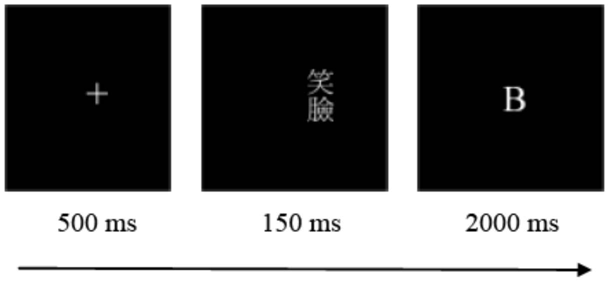

Figure1. Timing diagram of the experimental procedure

2.4 Event-related potential recording

The electroencephalogram was recorded from 64 electrodes embedded in an electro-cap(QuickCap, Neuromedical Supplies, Sterling, Texas, USA), referenced to the left and right mastoid, M1, M2 respectively. Positions of all the electrodes were arranged according to the international ten-twenty system. The electroencephalogram was continuously recorded and digitized at a rate of 500 Hz. The signal was amplified by SYNAMPS2 (Neuroscan Inc., El Paso, Texas, USA) with the band-pass set at 0.5–100 Hz. Blinks and eye movements were monitored via electrodes placed on the infraorbital ridges of the left eye (VEOG) and the outer canthus left and right electrode (HEOG). A ground electrode was placed on the forehead anterior to the FZ electrode. Electrode impedance was kept below 5 kohms.

2.5 ERP components

In the analyses of the ERP waveforms elicited by every stimulus in each condition, there were typically composed of a negative-going peak at around 100ms (N1), a positive-going peak at around 200ms (P200), a negative-going peak maximizing at around 400 ms (N400) over central and parietal electrode sites. Among these, N 170 was regarded as the early index for visual detection in word processing. In the current study, N170 was used to examine the manipulation of visual field. N400 was characterized as an index sensitive to language-related processing and was generally considered in response to violations of semantic expectations (Kutas and Hillyard, 1980). With the presentation of a semantically inappropriate or incongruent word, a large N400 activity would be elicited. In Huang et al. (2009), the 400 in the RH was regarded as sense competition because words with many senses elicit more negativity at around 400 ms.

3 Results

Behavioral accuracy below 70 percent and ERPs accepted trials below 16 were excluded from ANOVA analyses. Data from 28 of participants were used in the following behavioral and ERP analyses.

3.1 Behavioral data

A 2×2 (number of senses × visual field) analysis of variance (ANOVA) was performed on correct RTs and accuracy. For RTs, no significant main effect of number of senses ($F(1, 27) = 0.5$, $p=.48$) and interaction ($F(1, 27) = 1.33$, $p=.26$) was observed. A main effect of visual field reached marginally significance ($F(1, 27) = 3.38$, $p=.077$). Stimuli presented to RVF/ LH had the tendency to produce shorter response time than those presented to LVF/ RH. For accuracy, not any main effect or interaction was obtained.

3.2 ERP data

Temporal time windows of interest were N170 (150-180 ms) and N400 (350-500 ms). The mean amplitude of each time window from selected electrodes served as dependent measures in a repeated measures analysis of variance (ANOVA).

3.2.1 N170 (150-180 ms)

The mean amplitude of N170 was analyzed by ANOVA with factors of visual field (LVF/RVF), number of senses, and electrodes (P3/P4, P5/P6, P7/P8, PO5/ PO6). We obtained a significant visual field × electrodes interaction $F(7,189) = 45.34$, $p<.001$. Post-hoc comparison indicated that visual field simple main effects reached statistical significance in all electrodes (p's<.001). In electrodes on the left, P3, P5, P7, PO5, right visual field presentation elicited much greater negativity than left visual presentation and vice versa in electrodes on the right, P4, P6, P8, and PO8.

3.2.2 N400 (350-500 ms)

Mean amplitudes of all conditions were measured from 350 to 500ms and subjected to ANOVA with factors of visual field, the number of senses, electrodes, hemispheres. The midline analysis revealed marginal significance of two way interaction between the number of senses and visual field (F (1, 27) =3.83, p=.06). In the lateral analysis, there was marginal significance of visual field by number of senses interaction (F (1, 27) = 3.18, p=.086) and a marginally significant 4-way interaction of visual field, number of senses, electrodes and hemispheres (F (4, 108) =2.53, p=.072). Post-hoc comparisons showed that in the LVF/ RH few senses tended to be more negative than many senses (p<.05) while in the RVF/ LH, few and many senses did not reveal any difference (p=.73).

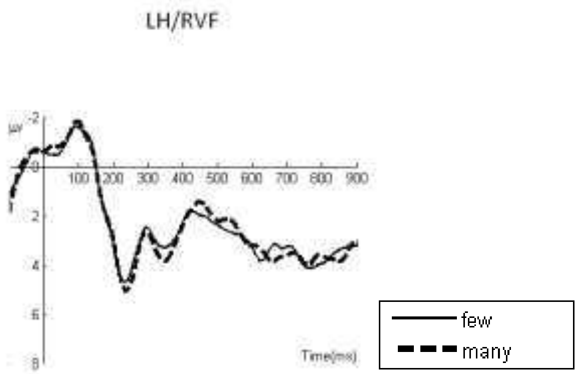

Figure 2—Grand averaged ERPs at CPZ in the RVF/LH.

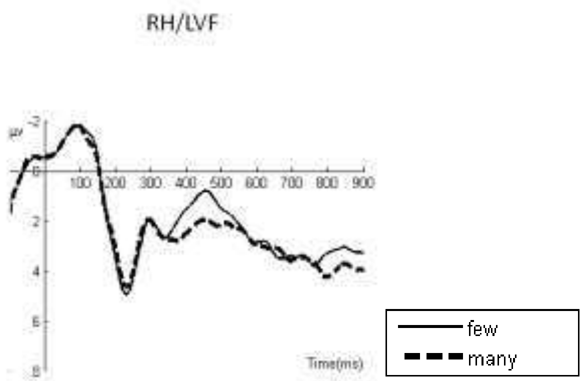

Figure 3—Grand averaged ERPs at CPZ in the LVF/RH

4 Discussion

In the behavioral data, no significant main effect of the number of senses and interaction was observed. Nevertheless, the ERP data demonstrated that there was marginal significance of two-way interaction (visual field × number of senses) and a marginally significant 4-way interaction. Post-hoc comparison showed that there were significant sense facilitation effects in the RH and no effect in the LH. ERP waveforms showed that words of few senses elicited more negativity than words of many senses around 400 ms in the RH, but the two conditions did not differ from each other in the LH.

The marginality of statistical significance led to the speculation in that the word category effect might dilute the sense effect in the experiment. Many studies, in general, suggested that the neural systems for lexical processing of nouns and verbs were anatomically distinct. For example, in children's lexical development, the acquisition of nouns seems to be earlier and easier than that of verbs (Gentner, 1982). In aphasic findings, case studies indicated that patients with lesions located in left anterior and middle temporal lobe, outside so called language areas, had difficulty in the production of nouns whereas patients with lesions areas in left frontal premotor cortex had difficulty in the production of verbs (Damasio & Damasio, 1992; Damasio et al., 1993). Evidence from event-related potentials also disclosed electrocortical differences between nouns and verbs over widespread cortical areas (Pulvermüller et al., 1999). Therefore, verbs were assumed to elicit stronger electrocortical activity around primary frontal, prefrontal areas associated with motor, premotor functions. Nouns, associated with concrete and well-imaginable meanings related to visual modality, were assumed to elicit larger electrocortical activity around visual cortices.

There was also evidence indicating that the conclusions were oversimplified. For example, Tyler et al. (2001, PET) found no significant action differences for nouns and verbs in lexical decision and semantic categorization task. Similarly, in an fMRI Chinese study, Li et al. (2004) pointed out that nouns and verbs were found to activate a wide range of overlapping brain areas and suggested distributed networks for either word class. One recent Chinese study on concreteness also showed similar distribution over the scalp for both nouns and verbs (Tsai et al., 2008).

The study was not meant to resolve the controversy of neural representations for nous and verbs. Instead, from the marginal significance of the data in the experiment, we speculated that the word class effect may influence the results, which led to the failure to reach significance in overall data. Therefore, we reanalyzed the data with the addition word class as one within-subject factor.

4.1 Re-analyses

To further examine the sense effect in nouns and verbs condition, separate analyses of ANOVA were carried out according to different word classes.

4.2 Behavioral data

A 2×2×2 (number of senses × visual field × word class) analysis of variance (ANOVA) was performed on correct RTs and accuracy. For RTs, results showed marginally significant effects for visual field ($F(1, 27) = 3.38$, $p=.077$) and word class ($F(1, 27) = 2.97$, $p=.096$) and for number of senses × word class interaction ($F(1, 27) = 2.94$, $p=.098$). Stimuli presented to the RVF/ LH tended to responded more quickly than to the LVF/ RH. Stimuli of nouns had shorter response time than stimuli of verbs. For accuracy analysis, nouns had significant higher accuracy than verbs (word class ($F(1, 27) =5.41$, $p<.05$).

4.3 ERP data

The grand mean ERPs elicited by few and many senses in RVF/ LH and LVF/ RH were presented in nouns and verbs separately.

4.3.1 Nouns

In the midline, there was a marginally significant number of senses × electrodes interaction ($F(4, 108) = 2.8$, $p<.08$). Lateral analyses indicated that there was a significant visual field × number of senses × electrode interaction ($F(1, 27) = 3.65$, $p<.05$). Planned comparison showed that only when stimuli presented to the LVF/ RH, few senses were more negative in C, CP, P (p's <.05 to <.01).

4.3.2 Verbs

In the midline analysis, there was no significant main effect of senses or interaction. In the lateral analyses, there were significant interactions of visual field × number of senses ($F(1, 27) =4.69$, $p<.05$) and visual field × number of senses × electrodes × hemispheres ($F(4, 108) = 4.23$, $p<.01$). Planned comparisons of four way interaction showed that when presented to LVF/ RH, few senses were more negative in F3, C3, CP3 and FC4 (p's<.05 to <.01) whereas when presented to the RVF/ LH, there was no difference between few and many senses.

5 Discussion

The purpose of additional analyses of sense effects in nouns and verbs was to examine clearer effects of senses without the confounding of the word class factor. The separate analyses for nouns and verbs both showed significant sense effects in the lateral sites. Furthermore, planned comparison of the senses demonstrated disparate distributions for nouns and verbs respectively. To be more specific, the sense effects for nouns were located in central-to-parietal areas of brain, whereas these effects for verbs primarily showed up in frontal, central, central-parietal electrodes on the left. The re-analyses of ERP data showed that the differences of distribution from either word category diluted the sense effect observed in the first analysis; therefore, the data was only marginally significant in the original analyses. Besides, though the current study was not meant to resolve the representations for different word categories, the additional results seemed to support the distinct neural representations for nouns and verbs, since each word class had its distribution for the sense effects. Certainly, further evidence of Chinese word class was required to approve the statement since there was also evidence suggesting distributed network for Chinese lexical processing (e.g. Li et al., 2004).

According to previous studies, different levels of processing in perception of words would lead to opposing results (e.g. Vitevitch and Luce, 1998; Cheng, 2006). Suppose the results were derived from the single entry representation of senses, the sense effect should be observed in the RH in the experiment since the depth of the task was changed. In other words, when subjects were undergoing a deeper level of lexical processing, the relatedness of senses might have been early processed in the LH due to the engagement in fine semantic processing; on the other hand, the sense effect might appear in the RH because its capacity allowed alternate meanings to maintain. Hence, in a deeper level of task, which slowed down the semantic processing, the facilitative sense effect was observed in the RH.

Overall, we suggested that the representation of Chinese senses be single entry and obtained the sense facilitation effects in LVF/ RH in which few senses were more negative than many senses both in nouns and verbs. We assumed that the results also provided empirical evidence indicating that the construction of Chinese WordNet has psychological validity.

6 Conclusions

The study attempted to find out whether the representation of senses in the RH was single-or separate-entry. When the depth of task was changed, the RH advantage for the processing of semantically related senses was observed. The finding was consistent with recent studies on the representation of polysemy (e.g. Beretta et al. 2005; Pylkkänen et al. 2006, Rodd et al., 2002).

Acknowledgments

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