Number of sense effects of Chinese disyllabic compounds in the two hemispheres

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1. Introduction

Lexical ambiguity is very common in language and is closely related to the issue of the nature of the mental lexicon in human brains. Linguistically, two different kinds of ambiguity are traditionally distinguished. One is called homonymy and the other is polysemy (Cruse, 1986; Lyons, 1977). The former means a lexical item having two or more semantically unrelated meanings. For instance, the word *bank* can refer to either a financial institution or the side of a river. The latter means that a lexical item has two or more related meanings, traditionally called ‘senses’. For example, the word *lamb* can be used to refer to ‘an animal’ or ‘meat’. In Chinese, homonymous examples such as *kuang1* has three unrelated meanings as enumerated in the Chinese Wordnet 1: (1) light as in *kuang1 xian4*; ‘streams of light’, *kuang1 liang4*; ‘light’; (2) naked as in *kuang1 jiao3*; ‘barefoot’, *zh1 ye4 kuang1 tu1*; ‘bare trees’; (3) simply as in *kuang1 ping2*; ‘hair turning white’. Polysemous examples derive from *tou2* meaning ‘head’ as in *tou2 lu2*, ‘a skull’; *tou2 ban3*, ‘the front page of a newspaper’, *x1 zhuang1 tou2*, ‘a kind of hairstyle’, *bai1 le tou2*, ‘hair turning white’ and so on.

Though there have many studies on lexical ambiguity of homonymy (e.g. Azuma & Van Orden, 1997; Borowsky & Masson, 1996; Jastrzembski, 1981; Millis & Button, 1989; Rubenstein, Garfield, & Millikan, 1970), the issue concerning polysemy has been much less studied. To date, it was generally assumed that unrelated meanings should be separately listed in separate lexical entries; nevertheless, it is unclear whether polysemous senses also have separate entries like homonymous meanings or if the related senses of a polysemy share a single lexical entry in the mental lexicon. In Chinese, most of the words are compounds and the constituent character within a compound word can also carry different meanings and/or related senses. Therefore, the specific question addressed in the study is to investigate how the number of related senses of constituent characters would influence Chinese compound word processing.

Recent psycholinguistic studies have examined early ambiguity disadvantage resulting from homonymy. These studies have further demonstrated that words having related senses resulted in facilitation in behavioral and magnetoencephalography (MEG) measurements (e.g. Beretta, Fiorentino, & Poppel, 2005; Pylkänen, Llinás, & Murphy, 2006; Rodd, Gaskell, & Marslen-Wilson, 2002). These studies are generally in agreement with the single-entry representation hypothesis for related senses for the following reasons. First, the senses are related to one another and are sometimes very similar (e.g. *lamb* as an animal and as meat). Second, the senses are historically derived from other
senses, which suggest a close relationship among senses (Lyons, 1977). Third, polysemy often forms morphological patterns across the lexicon, which is not true of homonyms (Pylkkänen et al., 2006). Fourth, it is suggested that different but semantically related senses are not explicitly represented in the lexicon but are derived by speakers through lexical rules (Caramazza & Grober, 1976; Nunberg, 1979). For example, the word paper may be represented as a single sense of sheets of writing material; the use of it can refer to a physical object like a newspaper or the content of a newspaper as in ‘the paper is dull’. In other words, the representation of senses exists “only one conventional use, with the other normal uses generated pragmatically” (Nunberg, 1979, p. 153). A similar proposal was made by Lehrer (1990), who claimed that polysemy can be largely explained through rules of meaning extension.

Pustejovsky (1995) argued that it was an entirely inadequate means to list senses in separate entries even though he observed that some theorists enumerated senses both for nouns and for variation in verb complementation. Besides, there were disadvantages in assuming separate-entry model for polysemy because Nunberg (1979) and Pustejovsky (1995) suggested that words can take on new senses more or less and that a single sense can have many syntactic realizations. However, there are also some problems in the single-entry assumption. Lyons (1977) suggested that the notion of relatedness among senses seemed to be a matter of degree rather than a clear-cut dichotomy and Nunberg (1979) indicated similar observations for polysemy in that “polysemy is a gradient phenomenon” (p. 142). In a series of experiments, Klein and Murphy (2001) and Klein and Murphy (2002) demonstrated that, when subjects were presented with a word in one sense, this would interfere with their later processing of the same word in a different sense. Furthermore, subjects did not judge the ‘nearly unrelated’ senses as the same kind of things. Therefore, it was possible that subjects might treat senses as unrelated meanings on an extreme of the degree of relatedness. These ideas seemed to challenge the single-entry hypothesis of senses.

The issue of polysemy representation is more complex in Chinese word recognition process. The statistics of the Chinese word corpus of Academia Sinica (1998) indicates that over 60% of the disyllabic compounds have at least one neighbor that shares either the first or second constituent character at the same position. Moreover, in contrast to alphabetic languages that words are composed of a small set of meaningless letters, Chinese words are composed of characters that can be mapped onto morphemes with clear boundaries. The resolution of lexical ambiguity has to consider the composition of constituent characters and how they contribute to the whole word reading since each character in Chinese has its morpheme(s) when they are embedded in two-character compounds.

Past studies on the lexical representation of compound words have also proposed that whereas each constituent character in a Chinese compound has its own orthographic, phonological and semantic representation, the whole word representation existed only at the semantic level (Zhou & Marslen-Wilson, 1994; Zhou & Marslen-Wilson, 1995). The activated semantic representation may include both the whole word and the constituent morphemes. According to Huang et al. (2006), the neighborhood size (NS) in Chinese compound words was defined as the number of neighbors which shared the same constituent character with the target word. The NS can be further divided into NS1 and NS2 based on whether these neighbors sharing the first or the second constituent character of the compound. For instance, a two-character word (e.g., 花市, hua1 shi4, flower market) can have some neighbors sharing the first constituent character (such as 花園, hua1 yuan2; flower garden) and some neighbors sharing the second constituent character (such as 都市, du1 shi4, city). The number of neighbors sharing the first constituent character is termed neighborhood size 1 (NS1) and the number of neighbors sharing the second constituent character is termed neighborhood size 2 (NS2). The regression analysis of Huang et al. (2006) has demonstrated that NS1 facilitated recognition while NS2 showed null effects. The results suggested that the neighborhood size of the first constituent character (NS1) played a more important role in lexical processing than did the neighborhood size of the second constituent character (NS2) in reading Chinese disyllabic compounds. This is further supported by Tsai, Lee, Lin, Tzeng, and Hung (2006) who manipulated the NS1 of words in a lexical decision task and in a sentence reading task that embedded the same set of words. Both response latencies and fixation durations displayed the facilitative NS1 effects. Words with large NS1 produced faster lexical response, higher skipping rate, and shorter fixation duration than those with small NS1.

Meanwhile, Huang (2005) demonstrated a clear interaction between NS1 and semantic transparency in lexical decision—specifically, a facilitative NS1 effect for transparent words, but an inhibitory NS1 effect for opaque words. These findings suggested that the role of neighborhood size in reading Chinese compound may not purely originate at the orthographic level; instead, constituent characters’ morphemes must additionally be considered. Indeed, a current study by Huang, Lee, Tsai and Tzeng (2011) demonstrated that, given the NS1 and word frequency were well matched, the number of different meanings of the first constituent character influenced the reading of Chinese compounds. To be more specific, the words with low sublexical ambiguity constituent characters elicited a more negative N400 than those with high sublexical ambiguity constituent characters when target words were centrally presented. Similar patterns were found when words were presented to the left visual field (right hemisphere). These findings indicate that a level of morphological representation between form and meaning needs to be established and refined in Chinese. In addition, hemispheric asymmetries in the use of word information in ambiguity resolution should be taken into account, even at the sublexical level (Huang et al., 2011). However, as we mentioned earlier, a character can stand for many distinct meanings or can stand for many related senses. It remains unclear how the number of related senses of the first constituent character affects the Chinese compound word recognition.

The other related issue addressed in the study is the role of two hemispheres in resolving semantic ambiguity. Different from the traditional view that only the left hemisphere (LH) was the language center (Broca, 1865), there are growing evidence using the visual half-field (VF) presentation technique to demonstrate that the right hemisphere (RH) has significant language processing strength (see Federmeier, Wloto, and Meyer (2008) and Lindell (2006) for a review). Previous literature introduced at least two different views considering the hemispheric asymmetries. One concerns the difference in processing speed as well as the time course of semantic activation while the other is based on the representational difference (fine coding versus coarse coding). The time course view assumed that over time, activation for distantly related information was suppressed in the left hemisphere but not in the right hemisphere. Burgess and Simpson (1988) found that in the automatic processing, only the LH engaged in the processing of ambiguous word meanings while in the controlled processing, the RH had a special role in ambiguity resolution to maintain alternate meanings. Koivisto (1997) showed a clear disassociation of a LH advantage in the early stage and a RH advantage in the late stage of categorically-related priming effects. The RH advantage in priming, also termed as a RH lag effect, was also found in other studies suggesting that lexical representations were activated more slowly in the right hemisphere than in the left (e.g., Abernethy & Coney, 1993; Collins, 1999).
In the representation account, Deacon et al. (2004) proposed that items were represented locally in the LH, whereas information regarding the same item was distributed across nodes in the RH. For the associated pairs (e.g. HONEY-BEE, SURGEON-SCALPEL), they observed significant N400 facilitation (reduced amplitudes for related, relative to unrelated, targets) in the LH but for the features-sharing pairs (e.g. TREE-BROCCOLI) they observed N400 facilitation in the RH. A follow-up study (Grose-Fifer & Deacon, 2004) also supported the RH’s advantage to process categorically pairs that shared features. Similarly, Faust and Lavidior (2003) demonstrated that the LH benefited mostly from semantically congruent primes related to dominant meaning of ambiguous targets whereas the RH benefited mainly 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 which focused on a single meaning interpretation, and the RH engaging in coarser semantic coding where multiple alternate meanings were activated.

Pylkkänen et al. (2006) were the first to focus on the investigation of how different but related senses were psychologically represented in the two hemispheres. Their results showed that in the LH, sense-relatedness elicited shorter latencies of the M350 source, which has been regarded as an index of lexical activation. On the other hand, in the RH, concurrent activity peaked later for sense-related than for unrelated stimuli, which Pylkkänen et al. interpreted as a potential sense competition effect. One possibility was that the RH activity performed some kind of conceptual selection but further experimentation was needed to narrow down on the interpretation of the RH activity. Their results were still in agreement with single-entry hypothesis and suggested that lexical processing was bilateral with different function in the LH and RH.

The present ERP studies examined how the related senses of the first character within compounds may be represented and processed in the two hemispheres by using the visual half-field (VF) presentation technique. The N400 component of ERPs was used to test our assumption of single-entry representation for related senses. N400 amplitude is regarded as an index of the difficulty of integrating semantic information. The larger the N400 the target elicits, the more difficult the task of lexical semantic integration. Likewise, when words appear in an incongruous sentence context, a larger N400 is elicited (e.g. Kutas & Hillyard, 1980). Meanwhile, literature on the concreteness effect (e.g. Tsai et al., 2009; West & Holcomb, 2000) and the neighborhood size effect (Holcomb, Grainger, & O’Rourke, 2002) have demonstrated that the more attributes the word has, the larger N400 amplitudes are elicited. According to the single-entry hypothesis, if a word has more semantically related senses, the stronger semantic relatedness within a morphological root will thus accelerate the recognition of a morpheme. Therefore, we predict that the more related senses a constituent character has the less negativity the N400 of the word may show.

2. Experiment 1

Experiment 1 aims to examine whether the number of senses of the first character in Chinese compounds have separate entries or single entry and to investigate the hemispheric processing of semantically related senses in Chinese disyllabic compounds by using the visual half-field (VF) presentation technique. To this end, the number of related senses (few versus many) of the first constituent characters in two-character compounds and the visual field (LVF vs. RVF) were manipulated in the lexical decision task. Given previous works have demonstrated an ambiguity disadvantage for homonymous words and suggested that unrelated meanings were listed in separate entries, the sense advantage for polysemous words was found (Beretta et al., 2005; Rodd et al., 2002) and implied that related senses are stored as a single core meaning. The facilitative number of sense effect, which shows reduced N400 for reading word with many related senses in its first constituent character, will be expected.

2.1. Participants

Twenty-one graduate and undergraduate students (all male, aged 18–28, mean 22.62) were paid for their participation. All were right-handed native Chinese speakers with no history of neurological or psychiatric disorders.

2.2. Materials

A list of 120 Chinese disyllabic compound words was selected from the Academia Sinica balanced corpus (Huang & Chen, 1998). The words were divided into four subsets according to visual field (LVF/RVF) and number of senses of the first character (few senses/many senses; mean 1.98/11.30). Possible confounding factors of word frequency, neighborhood size of the first characters (NS1) and of the second characters (NS2) were matched. The examples and stimuli characteristics were listed in Table 1.

One hundred and twenty pseudowords were created as NO trials in the lexical decision task by concatenating two characters that do not occur in the word corpus. Mean values of NS1 and NS2 were both matched for the real words. Possible confounding factors such as NS1, NS2 and the number of meanings corresponding to the second character were controlled. Pronunciation of pseudowords was created not to resemble that of the real words. Practice trials contained 20 words and 20 pseudowords.

2.3. Procedure

Participants were tested in a single experimental session conducted in a sound-proof, electrically-shield chamber. They were seated in a comfortable chair 60 cm in front of a monitor and instructed to read Chinese compounds for comprehension. Three hundred and sixty randomized experimental trials were presented in four separate blocks (word: pseudoword: number = 1:1:1). Each trial began with a white cross presented centrally for 500 ms and was followed by the presentation of the targets for 150 ms, randomly appearing in the LVF/RVF. The disyllabic compounds were vertically arranged in the LVF or RVF with inner edge two degrees of visual angle from fixation. It was very important to ensure that each character in the compound targets was equally distant from the central presentation. At the end of each trial, a capital B was pre-

<table>
<thead>
<tr>
<th>Example of stimuli</th>
<th>Few senses</th>
<th>Many senses</th>
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<tbody>
<tr>
<td>Senses of the 1st character</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(1) smile, (2) ridicule</td>
<td>xiao1 lian3</td>
<td>shou3 ling3</td>
</tr>
<tr>
<td></td>
<td>(1) head,</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(2) beginning,</td>
<td></td>
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<tr>
<td></td>
<td>(3) foremost,</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(4) first,</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(5) side, etc.</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>No. of senses of the 1st character</th>
<th>Few senses</th>
<th>Many senses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Word frequency</td>
<td></td>
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<tr>
<td>Neighborhood size 1 (NS1)</td>
<td>15.39</td>
<td>15.42</td>
</tr>
<tr>
<td>Neighborhood size 2 (NS2)</td>
<td>14.81</td>
<td>18.55</td>
</tr>
</tbody>
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Table 1

Design of stimuli in experiment 1. Mean values for the number of senses of the first character, word frequency of the compounds, NS1 (the number of neighbors sharing the first constituent character), NS2 (the number of neighbors sharing the second constituent character), and one example of the stimuli in each condition.
presented in the center of the screen for 1500 ms. Participants were asked not to blink their eyes until the appearance of the capital B to minimize the interference of eye movement artifacts. There was a 500 ms blank interval between the target and the capital B.

Participants were instructed to judge whether they could recognize the compound targets or not. If the answer is positive, they should press the response box with both of their index fingers. If not, they should press the response box with both of their middle fingers. Response time and event-related potentials data were both collected during the process. Occasionally, a 9 pt. digit was presented, instead of a word, on the center of screen where participants should have been fixating. Participants were instructed to judge whether the numbers were more than or less than five. If the number is less than five, they should press the response box with both of their index fingers. If it is more than five, they should press the response box with both of their middle fingers. Data from any participant who did not respond to the digits with an acceptable accuracy of 70% were excluded. This design was to ensure that participants were fixating the designated fixation point and to ensure presented word would be initially contralaterally projected to different hemispheres. Before the experiment, we also explicitly explained to each participant the importance of fixating the designated fixation point at all times when they see the cross.

2.4. EEG recording and analysis

The electroencephalogram (EEG) was recorded from 64 electrodes mounted on an electrode cap (QuickCap, Neuroomedical Supplies, Sterling, USA) with a common vertex reference and was re-referenced to the average of the left and right mastoids for off-line analysis. The EEG was continuously recorded and digitized at a rate of 500 Hz and the signal was amplified by SYNAMPS2. (Neuroscan, Inc.) amplifiers with the band-pass at 0.05–100 Hz for off-line analysis. Eye movements and blinks were monitored with supra- and infra-orbital electrodes and with electrodes in the external canthi. Electrode impedances remained below 5 kΩ.

Epochs started 100 ms prestimulus, lasted to 922 ms, and used the 100 ms prestimulus for baseline correction. Artifact rejection was performed in three stages. The first stage was eye-movement rejection in which trials with voltage variations larger than ±100 μV in either VEOG or HEOG were rejected. In the second stage, during 0–200 ms when the target was presented, if there were signals larger than ±80 μV, the trials would be regarded as horizontal eye movements and rejected. In the third stage trials with voltage variations larger than ±60 μV in at least one of the rest of the channels were rejected. The data were then band-pass filtered between 0.01 and 30 Hz (zero phase shift mode, 12 dB/oct). By averaging over corresponding trials, ERPs were computed for every subject, electrode and experimental condition for correct trials only. Statistical analyses were performed on mean amplitudes in the N400 window after Geisser-Greenhouse correction.

2.5. Results

There were two main criteria to reject artifacts. Each subject had to pass both behavioral and ERP data criteria. In the behavioral data, if the correctness in any condition is below 70%, the data from that participant would be excluded. Second, if the ERP accepted trials in any condition were below 16, that participant would be excluded too. After removing participants who failed to pass these criteria, there were 18 participants in the final statistical analyses.

2.6. Behavioral data

Mean correct reaction times and accuracy from eighteen participants were presented in Table 2. Analyses of variance (ANOVAs) with the within-subject factors of visual field (LVF vs. RVF) and the number of senses (few versus many) were performed on correct RTs and accuracy. For RTs, no significant main effects of the number of senses (F (1, 17) = 0.57, p = .46) and visual field (F (1, 17) = 1.55, p = .23) were observed. Interaction between the number of senses and visual field did not reach significance. For accuracy, no significant main effects (number of senses, F (1, 17) = 0.27, p = .61; visual field, F (1, 17) = 0.03, p = .86) and interaction (F (1, 17) = 0.27, p = .61) were observed.

For the lexicality effect, analyses using repeated measures ANOVA with within-subject factors of lexicality (words versus pseudowords) and visual field (left versus right) were performed. There was a significant lexicality main effect (F (1, 17) = 10.99, p < .01). Response time to real words was faster than to pseudowords. The main effect of visual field (F (1, 17) = 0.22, p = .64) and interaction between lexicality and visual field (F (1, 17) = .77, p = .39) did not reach statistical significance. Neither main effects nor interactions were significant for accuracy analysis (all Fs < 1).

2.7. Event-related potentials

Temporal windows for N1 (150–180 ms) and N400 (350–550 ms) were ERPs components of interest. N1 is a negative-going deflection occurring between 100 and 150 ms (N1) from the stimulus onset. In the lateral occipital lobe, there were electrodes peaked from 150 to 180 ms (P3/P4, P5/P6, P7/P8, P05/P06) indexed as N1 and viewed as one component reflecting the visual field effects. The N400 was the primary index to examine the sense facilitation. The mean amplitude of each time window from selected electrodes served as dependent measures in repeated measures ANOVAs. For each ANOVA, the Greenhouse-Geisser adjustment to the degrees of freedom was applied to correct for the violations of sphericity associated with repeated measures. Accordingly, for all the F tests with more than one degree of freedom in the numerator, the corrected p-value is reported. The post-hoc tests were carried out using Tukey’s procedure.

2.7.1. N1

To assess whether the lateralized presentation of the target words was effective in stimulating the contralateral hemisphere, one can examine visual potentials such as the N1. The N1 was presumed to reflect extrastriate visual processing and was largest contralateral to the VF of stimulation (Hillyard & Anllo-Vento, 1998). The mean amplitude of N1 was analyzed by a three-way ANOVA with visual fields (LVF/RVF), number of senses, and electrodes (P3/P4, P5/P6, P7/P8, P05/P06) as within-subject factors. The data showed that there was a two-way interaction between visual field and electrodes (F (7, 119) = 33.06, p < .001). Post-hoc comparison indicated that visual-field simple main effects reached statistical significance in all electrodes (p’s < .001). In the electrodes on the left: P3, P5, P7, P05, targets of RVF presentation elicited much greater negativity than that of LVF. In the electrodes on the right:
P4, P6, P8, PO8, the patterns became opposite. There was no main effect of number of senses on the N1.

2.7.2. N400

The analyses of N400 were conducted separately on the data of midline and lateral lines. In the midline analyses of N400, within-subject factors of visual field, number of senses, and 5 electrodes (FZ, FCZ, CZ, CPZ, PZ) were used; in the lateral analyses, factors included visual fields, number of senses, electrodes (F3/4, FC3/4, C3/4, CP3/4, P3/4), and hemispheres (Left/Right). A significant two-way interaction between visual field and number of senses was observed in the midline ($F(1, 17) = 10.15$, $p < .01$) and marginally significant in the lateral ($F(1, 17) = 4.2$, $p = .056$). Three-way interactions among visual field, number of senses, and electrodes also reached significance in both midline ($F(4, 68) = 5.56$, $p < .01$) and lateral ($F(1, 17) = 6.14$, $p < .01$).

Post-hoc comparison of three-way interaction indicated that in the LH/rvf, few senses were more negative than many senses in the electrodes of CPZ, P3, PZ, P4 ($p's < .01–.001$) and marginally more negative in CP3, CP4. In the RH/lvf, however, many senses were more negative than few senses in FCZ, CZ, CPZ, PZ ($p's < .05$) and marginally more negative in C4.

2.8. Discussion

Experiment one aims to examine the representation of related senses of the first characters embedded in Chinese compounds and to investigate the hemispheric processing of the number of senses in the two hemispheres. ERP components of N1 and N400 were used to index the on-line brain activities. In Fig. 1, the opposite patterns of N1 in posterior electrodes PO5 and PO6 demonstrated the visual field effect and ensured that targets presented laterally were projected onto the corresponding hemispheres. As for the number of sense effect, under the single-entry hypothesis for related senses, a facilitative sense effect was expected. In the behavioral data; however, there was neither significant sense main effect nor the interaction between visual field and the number of senses. We suggested that it might be due to the fact that we were looking for the sense effect from the single characters embedded in compounds rather than from the whole word level. Therefore, it was not easy to observe sense advantage through our behavioral data.

Importantly, though there was no significant sense effect in reaction times, we had some evidence from the ERP results as shown in Fig. 2. The data in the LH/rvf showed that targets of many related senses elicited less negative N400s than few senses while the RH/lvf showed the opposite patterns. The pattern in the LH implied that activation of these senses became benefits of reverberations of relatedness among senses and facilitated compound processing. The finding was regarded consistent with previous single-entry assumption (e.g. Beretta et al., 2005; Klepousniotou, 2002; Pylkkänen et al., 2006; Rodd et al., 2002). However, the results in the RH/lvf showing that many senses were more negative than few senses in the N400s could be interpreted as inhibition but contradictory to our prediction of sense representation. Pylkkänen et al. (2006) obtained similar results in their MEG study. While sense facilitation was found in the LH, the RH data at 300–400 ms were suggestive of a potential sense competition. The competition effect in the RH seemed to allow for separate-entry representation for senses. Nevertheless, Pylkkänen et al. (2006) attributed this phenomenon to the hemispheric processing characteristics in the RH and suggested that the representation of senses be single entry and that the patterns in the RH may be due to some type of conceptual selection of hemispheric processing. They reasoned that, in the single entry framework, while processing of the sense effect was assumed to yield facilitation, processing might also involve selection between separately listed senses within single entry where the relatedness may be weakened.

The other possible explanation for the sense effect in the RH might be related to the task demands. In lexical decision tasks, subjects might make their judgments based on perceptual familiarity rather than the involvement of lexical access. Grainger and Jacob's (1996) introduced a 'fast guess' mechanism in their multiple readout model (MRM), which can lead to a 'yes' response even before any specific word representation has reached the threshold criteria. That is, a lexical decision can be made even before lexical identification is fully complete. Therefore, we assumed that the patterns in experiment 1 may result from hemispheric processing characteristics because of a low-demanding task. In the review of brain asymmetry in lexical processing, the LH was regarded
sophisticated in fine, convergent semantic coding while the RH was engaged in coarse, divergent semantic processing (e.g. Beeman 1998; Beeman & Chiarello, 1998; Bouaffre & Fat-Justiceba, 2007; Faust & Lavidor, 2003). The semantic representation in the two hemispheres (Deacon et al., 2004) also seemed reasonable to account for the asymmetric patterns with the local, holistic semantic representation in the LH and the distributed, feature-based connection in the RH. The pattern in the RH may represent the complementary activation of semantic features in accordance with the hemispheric processing characteristics. In other words, characters with many related senses may elicit greater N400 in the RH because there were more links to different features rather than greater competition among senses. However, it was uncertain whether the opposite patterns resulted from different semantic representations or resulted from hemispheric asymmetries in resolving sub-lexical sense ambiguity. In terms of processing efficiency, the LH was fast in targeting the primary, focused lexical information and related associations while the RH was relatively slow because it had the tendency to maintain multiple meanings of words or related features (e.g. Abernethy & Coney, 1993; Collins, 1999; Koivisto, 1997). Therefore, we assumed that if the task requires deeper processes such as accessing a word’s lexical information, we may have the opportunity to observe the sense facilitation in the RH.

3. Experiment 2

To clarify the influence of task demands, we deepened the difficulty of the task by using the word class judgment task. As mentioned, in lexical decision tasks, participants might make their judgments based on the perceptual familiarity. The influence of lexical access is uncertain. Participants in experiment 2 were asked to decide whether the targets belonged to verbs or nouns, which required participants to make their decisions not simply relying on word familiarity but on the retrieval of lexical information. Given the proposed functional asymmetry of two hemispheres in resolving the semantic ambiguity, the processing speed in the LH was fast while the RH processed semantic information relatively slow (e.g. Abernethy & Coney, 1993; Collins, 1999; Koivisto, 1997). We predict that it may be easier to observe the facilitative sense effect in the RH in a high-demanding task.

3.1. Participants

Thirty-eight graduate and undergraduate students (18–28 years of age, mean age 22.39) took part in the experiment. Other requirements were the same as experiment one: male, right-handedness, no history of neurological or psychiatric disorders, and normal or corrected-to-normal vision. Written consent was obtained from all participants.

3.2. Materials

Experiment 2 manipulated visual field (RVF vs. LVF) and the number of senses of the first character constituent of Chinese disyllabic compounds. Materials consisted of 120 compounds, two-way designed (few/many senses; RVF/LVF) and counterbalanced with word class. 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 of word frequency, neighborhood size of the first characters (NS1) and of the second characters (NS2) were well matched. The stimuli characteristics were listed in Table 3.

The task in experiment 2 required participants to judge whether the target belonged to verbs or nouns. Nevertheless, in Chinese,
there exists controversy over the distinction of verbs and nouns. To avoid this problem, we labeled the target compounds as noun (or verb) if the percentages of that compound is the dominant one and makes up more than 95% of the usage in the balanced corpus of Academia Sinica in Taiwan (Huang & Chen, 1998). Secondly, a pilot pretest was given to another group of participants to exclude these possibly confused choices. These participants were asked to use their language intuition to write down their word class judgments in a paper sheet containing 120 targets. Words that having ambiguous answers were replaced by other valid target words.

3.3. Procedure

The procedure in experiment 2 was the same as experiment 1 except that the task was changed. In experiment 2, participants were instructed to judge whether the compound presented was a noun or a verb. For odd-number participants, 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 participants, the instruction was opposite. To control the central fixation of eyes, a 9 pt. digit was also occasionally presented on the center of screen where participants should have been fixating. Odd-number subjects should press the response box with both of their index fingers when number 6–9 was presented centrally on the screen and with both of their middle fingers when number 1–4 was on the screen. For even-number subjects, instruction reversed. Data from any participant who did not respond to the digits with an acceptable accuracy of 70% were excluded. Again, this design was to ensure that participants were fixating the designated fixation point and to ensure presented word would be initially and contralaterally projected to different hemispheres. Response time and event-related potentials data were both collected during the process.

3.4. Results

There were five participants whose behavioral data were below 70% and five participants whose ERP accepted trials were lower than 16 per condition due to eye blinks. Therefore, there were more participants excluded from the final analysis in experiment 2. Data from 28 of participants were used in the following behavioral and ERP analyses.

3.4.1. Behavioral data

Mean correct reaction times and accuracy from 28 participants were presented in Table 4. Analyses of variance (ANOVA) with the within-subject factors of visual field (LVF vs. RVF) and the number of senses (few versus many) were 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 LH/rvf had the tendency to produce shorter response time than those presented to RH/lvf. For accuracy, not any main effect or interaction was obtained ($Fs < 1$).

3.4.2. ERP data

Temporal time windows of interest were N1 (150–180 ms) and N400 (350–500 ms). The mean amplitude of each time window from selected electrodes would serve as dependent measures in a repeated measures analysis of variance (ANOVA).

3.4.2.1. N1. As experiment 1, we examined the N1 component to assess whether the lateralized presentation of the target words was effective in stimulating the contralateral hemisphere. The mean amplitude of N1 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 by electrodes interaction $F(7, 189) = 45.34, p < .001$. Post-hoc comparison indicated that the simple main effects of visual field reached statistical significance in all electrodes ($p's < .001$). In electrodes on the left, P3, P5, P7, PO5, RVF presentation elicited much greater negativity than LVF presentation and vice versa in electrodes on the right, P4, P6, P8, and PO8. There was no number of senses effect in this component.

3.4.2.2. N400 (350–500 ms). Grand averaged ERPs in the LH/rvf and RH/lvf in experiment 2 were presented in Fig. 3. Mean amplitudes of all conditions were measured from 350 to 500 ms and subjected to ANOVA with factors of visual field, the number of senses, electrodes, and 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 ($F(1, 27) = 3.18, p = .08$) and a marginally significant 4-way interaction of visual field, number of senses, electrodes and hemispheres ($F(4, 108) = 2.53, p = .07$). Post-hoc comparisons showed that in the RH/lvf few senses tended to be more negative than many senses ($p < .05$) while in the LH/rvf, few and many senses did not reveal any difference ($p = .73$).

3.5. Discussion

The goal of experiment 2 was to examine if there was sense facilitation in the RH to support the single-entry hypothesis in the word class judgment task which emphasized more on the process of lexical retrieval. For the main concern of semantic processing on N400s, we regarded that the sense effect might occur in the RH due to its nature of relative slow processing speed and the higher task demand in experiment 2. In the comparison of the average RTs in the two experiments, it took averagely 793.09 ms for participants in experiment two to make their decisions while it took a shorter period of time of 706.37 in experiment one. The increase of response time as well as the fact that more participants did not pass both of the criteria demonstrated that the task was more difficult.

Although no significant main effect of number of senses and interaction was observed in the behavioral data, the ERP data demonstrated that there was marginal significance of two-way interaction (visual field $\times$ number of senses) and a marginally significant 4-way interaction. The planned 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. The results supported the single-entry representation for senses in a deeper level of lexical processing.

However, the marginality of statistical significance between VF and number of senses led to the speculation that the word category
effect might dilute the sense effect in experiment 2. In neuropsychological studies, a double dissociation between deficits of nouns and verbs has been reported on aphasic patients at the lexical level (e.g., Caramazza & Hillis, 1991; Chen & Bates, 1998; McCarthy & Warrington, 1985; Miceli, Silveri, Nocentini, & Caramazza, 1988; Zingeser & Berndt, 1990). Many studies, in general, suggested that the neural systems for lexical processing of nouns and verbs were anatomically distinct (but see Li, Jin, & Tan, 2004; Tyler, Russell, Fadili, & Moss, 2001). For example, the aphasic studies demonstrated that patients with lesions located in left anterior and middle temporal lobe had difficulty in the production of nouns whereas patients with lesions in left frontal premotor cortex had difficulty in the production of verbs (Damasio & Damasio, 1992; Damasio & Tranel, 1993). Evidence from event-related potentials also disclosed that nouns were associated with more intensified N400 than verbs over centro-parietal sites, and verbs elicited enhanced positivity at the left frontal sites (e.g., Federmeier, Segal, Lombrozo, & Kutas, 2000; Lee & Federmeier, 2006; Pulvermuller, Lutzenberger, & Preisl, 1999). Pulvermuller et al. (1999) attributed the neurophysiological differences between nouns and verbs to different semantic networks (e.g., motor and visual associations) supporting the distinctions between these two word classes. 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 electrophysiological activity around visual cortices. Others explained such an effect by the concreteness/imageability between nouns and verbs. The processing of concrete words involves two systems: a verbal semantic system and an imagistic system, whereas the processing of abstract words lacks the assistance from the imagistic system. Thus, the neural signals observed in the frontal sites is associated with imageability effects, whereas the effects observed in the central–posterior sites are associated with processing in the verbal system (Federmeier et al., 2000; Lee & Federmeier, 2006). In the previous analysis, the data from noun and verb were pooled together. We speculated it might lead to the marginal significant word class effect. Therefore, we reanalyzed the data with the word class as an additional within-subject factor.

3.6. Re-analyses

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

3.6.1. Behavioral data

A $2 \times 2 \times 2$ (number of senses × visual field × word class) 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 the interaction between number of senses and word class ($F(1, 27) = 2.94, p = .098$). Stimuli presented to the LH/rvf tended to respond more quickly than to the RH/lvf. Stimuli of nouns had shorter response time than stimuli of verbs. For accuracy analysis, nouns had significant higher accuracy than verbs (word class ($F(1, 27) = 5.41, p < .05$).

3.6.2. ERP data

The grand mean ERPs elicited by few and many senses in LH/rvf and RH/lvf were analyzed in nouns and verbs separately. Grand averaged ERPs for nouns and verbs were presented in Figs. 4 and 5.

3.6.2.1. Nouns.

In the midline analysis, 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 ($F(1, 27) = 3.65, p < .05$). There were no significant simple main effects of number of senses in the LH and RH. In the LH, there was no significant simple interaction; in the RH, however, there was a number of senses by electrodes interaction ($F(4, 108) = 5, p < .01$). Planned comparison showed that only when stimuli presented to the RH/lvf, few senses were more negative in C3, C4, CP3, CP4, P3, and P4. ($p's < .05$ to $<.01$).

3.6.2.2. Verbs.

In the midline analysis, there was no significant main effect of senses or interaction. In the lateral analyses, there was a significant interaction of visual field × number of senses ($F(1, 27) = 4.69, p < .05$). There was also a significant interaction of
visual field × number of senses × electrodes × hemispheres (F (4, 108) = 4.23, p < .01). In the LH, there was no significant simple interaction, but in the RH, there was a number of senses × electrodes × hemispheres three-way interaction (F (4, 108) = 3.85, p < .001). Planned comparisons of four way interaction showed that when presented to the RH/lvf, few senses were more negative in F3, C3, CP3 and FC4 (p's < .05 to <.01) whereas when presented to the LH/rvf, there was no difference between few and many senses.

3.7. Discussion for the re-analysis

The purpose of additional analyses of the sense effects in nouns and verbs was to examine clearer effects of senses without the...
confounding from the word class factor. The separate analyses for nouns and verbs both showed significant sense effects in RH/lfv in which words with few senses of initial constituent character elicited more negative N400s than those with many senses of initial constituent character but with different topographic distributions. 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 disparity of distribution seemed consistent with the distinction in previous studies (Damasio & Damasio, 1992; Damasio & Tranel, 1993; Federmeier et al., 2000; Lee & Federmeier, 2006; Pulvermüller et al., 1999). In a high-demanding task of the word class judgment, we further demonstrated that the RH had the advantage to show the sense effect because its processing was relatively slow and can maintain alternate meanings or related features (Abernethy & Conney, 1993; Bouaffre & Fa ta-Ainseba, 2007; Collins, 1999). In particular, we found null effects in the LH. When participants were undergoing a deeper level of lexical processing, the relatedness of senses might have been early processed in the LH due to the fine semantic processing.

The re-analyses of ERP data explained that the differences of distribution from either word category diluted the sense effect observed in the first analysis, so the data were only marginally significant in the original analyses. Though the current study was not 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 experimentation was required to verify the pattern since there was also evidence suggesting a distributed network for nouns and verbs in Chinese lexical processing (e.g. Li et al., 2004).

4. General discussion

The study aims to investigate the representation of related senses of the first character in Chinese compounds and the bi-hemispheric processing of the sense effect. Previous studies have overlooked two types of ambiguity (Azuma & Van Orden, 1997; Borowsky & Masson, 1996; Jastrzembski, 1981; Millis & Button, 1989; Rubenstein et al., 1970) and obtained mixed results. More recent studies suggested that the semantic relatedness of senses resulted in the advantage effect (Beretta et al., 2005; Kleponsiotou, 2002; Pyllkkänen et al., 2006; Rodd et al., 2002) The separate-entry account assumed that the representation of polysemous senses was comparable to that of homonymous meanings since they both involve separate lexical entries. Processing of both kinds of ambiguity should be the same and obtain inhibitory effects for words of many meanings. Alternatively, the single-entry account held the view that the representation of polysemous senses should be different from that of homonyms. The presence of many related senses within one single entry should benefit word recognition and result in facilitation. Recent studies (Beretta et al., 2005; Kleponsiotou, 2002; Pyllkkänen et al., 2006; Rodd et al., 2002) have clarified distinct representations for homonymous (separate-entry) and polysemous (single-entry) words. In the current study, the results obtained in both experiments are consistent with the single-entry representation for related senses on recent studies of polysemy.

In reading Chinese compound, morphological and semantic influences are often interlaced. A constituent character has its own morphemes and is combined with other constituent characters to form compound words. Huang et al. (2006) proposed that the NS1 played a more important role than NS2 in Chinese compound processing. As previous studies have suggested (Huang, 2005), the neighborhood size effect was not purely originated at the orthographic level; instead, we must also consider influence from constituent characters’ morphemes. In a follow-up study, Huang et al. (2011) demonstrated the homonymous effect from the first characters within Chinese compounds. The value of this study showed that the number of senses of the first constituent characters also played a role in Chinese compound processing and that, more importantly, the richness of related senses of the first character can facilitate the whole word processing. Taken together, we clarified that constituent characters can affect the compound word processing and suggest that the resolution of sublexical ambiguity may differ according to whether the constituent character is homonymous or polysemous.

Furthermore, the present ERP patterns have demonstrated very interesting hemispheric asymmetries in the low-demanding task of lexical decision and in the high-demanding task of word class judgment. In the low-demanding task of lexical decision, the N400s in the LH and the RH were opposite with the few senses more negative in the LH and many senses more negative in the RH. If the result in the LH was interpreted as the benefits from the presence of many related senses, the fact that, in the RH, many senses were more negative than few senses in the N400s seemed to be sense inhibition and contradictory to our prediction. However, this finding can be explained by the fine/coarse coding hypothesis in the LH and the RH (Beeman 1998; Bouaffre & Fa ta-Ainseba, 2007) or the local/distributed semantic representation in the LH and RH (Deacon et al., 2004). The patterns found in the RH in lexical decision task may not be due to sense competition but due to the greater activation of features associated to the larger number of related senses. As the concreteness effect (e.g. Tsai et al., 2009; West & Holcomb, 2000) and the neighborhood size effect (Holcomb, Grainger, & O’Rourke, 2002) suggest, the more attributes the word has, the larger N400s are elicited. Once the depth of the task was changed to a word class judgment, our results also demonstrated the nature hemispheric efficiency in the resolution of related senses because the LH has the advantage in the early stage processing while the RH has the advantage in the late stage processing (e.g. Abernethy & Conney, 1993; Bouaffre & Fa ta-Ainseba, 2007; Collins, 1999; Koivisto, 1997). Therefore, in a high-demanding task, it seemed natural that, in the LH, semantic relatedness from senses had been resolved and thus showed null effects. This is especially true since the LH tends to quickly process focused meanings, which coincides with our primary concern in the resolution of related senses. Meanwhile, given the processing speed is relatively slow in the RH in comparison with that in the LH, it is more likely to observe the number of sense effect in the RH. Taken together, the results in the two experiments support the single lexical entry representation for senses and demonstrate hemispheric asymmetries in different task demands. Most importantly, our findings demonstrate that the number of related senses of the first constituent characters play a role in Chinese compound processing. Furthermore, our results distinguish from the observations in Huang et al. (2011) which showed the sublexical ambiguity for homonymous, unrelated meanings. It seems that the two types of sublexical ambiguity display opposite effects in reading Chinese compounds; one is sublexical sense advantage effects whereas the other is sublexical semantic ambiguity disadvantage. Future work to investigate how these sublexical properties are represented in models for Chinese compound word recognition and how they interact with each other in the mental lexicon are needed.

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