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Processing the Chinese language: An introduction

Xiaolin Zhou
Centre for Brain and Cognitive Sciences and Department of Psychology; Key Laboratory of Machine Perception and Intelligence, Ministry of Education; and Key Laboratory of Computational Linguistics, Ministry of Education, Peking University, Beijing, China

Zheng Ye
Centre for Brain and Cognitive Sciences and Department of Psychology, Peking University, Beijing, China

Him Cheung and Hsuan-Chih Chen
Department of Psychology, The Chinese University of Hong Kong, Shatin, NT, Hong Kong, China

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The Chinese language possesses linguistic properties that are distinct from those of the most widely studied European languages. Given such uniqueness, research on the neurocognitive processing of Chinese not only contributes to our understanding of language-specific cognitive processes but also sheds light on the universality of psycholinguistic models developed on the basis of these European languages. In this Introduction, we briefly review neurocognitive studies on the processing of Chinese in the past ten years, summarizing existing findings concerning lexical, sentential, and discourse processing in Chinese.

Keywords: Chinese; Lexical processing; Sentence processing; Discourse processing; Event-related potential; Functional magnetic resonance imaging.

Ten years ago, the senior editors of this issue edited a special issue on the processing of East Asian languages for *Language and Cognitive Processes* (Chen & Zhou, 1999). Since then there have been exponential developments in the neurocognitive study of Chinese, Japanese, and Korean. These developments can be observed in the scope, quality, and quantity of

Correspondence should be addressed to Dr Xiaolin Zhou, Department of Psychology, Peking University, Beijing 100871, China. E-mail: xz104@pku.edu.cn

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research, and also in the variety of techniques employed, including eye tracking, event-related potential (ERP) recording, and functional magnetic resonance imaging (fMRI). The present volume presents only a biased, restricted sample of these new developments. In this introduction, we review briefly studies from the last ten years on the lexical processing of Chinese characters and compound words, and studies on sentence and discourse processing. These studies form the foundation for other aspects of research on Chinese, including bilingualism and brain imaging.

LEXICAL PROCESSING

Word recognition

Given the uniqueness of the Chinese logographic writing system, cognitive and neural processes underlying the recognition of Chinese characters are among the first to attract psychologists to the Chinese language. The starting point of this field was the issues framed according to the dual-route model of reading (Coltheart, 1978): to what extent phonological mediation plays a role in constraining semantic activation in reading Chinese and how sub-lexical processing of radicals in Chinese characters contributes to phonological activation of whole characters. The widely accepted, intuitive thinking before and in the 1980s was that Chinese characters are recognised predominantly through direct mapping between orthographic information and lexical semantic representation. In the 1990s, a few psychologists, among them Perfetti and his colleagues, were influenced by findings in reading alphabetic words (Lesch & Pollatsek, 1993; Lukatela & Turvey, 1991, 1994; Van Orden, 1987; Van Orden, Johnston, & Hale, 1988) and began to argue for a 'universal role' of phonology in reading (Perfetti, Tan, Zhang, & Georgi, 1995). According to these authors, phonological information in Chinese, as that in alphabetic scripts, is activated earlier than semantic information and access to lexical semantics depends almost exclusively on phonological activation (Perfetti & Zhang, 1995; Perfetti & Tan, 1998; Tan, Hoosain, & Siok, 1996). These arguments, however, hinged upon data that were mostly not replicable (see Chen & Shu, 2001; Xie & Zhou, 2003; Zhou & Marslen-Wilson, 2000a). Moreover, the priority of phonology in lexical processing of Chinese was challenged by case studies which showed that brain-damaged patients suffering from phonological deficits could be intact in understanding the meaning of visually presented words (e.g., Han & Bi, 2009), and that brain-injured anomic individuals with largely preserved reading abilities could produce legitimate responses to pseudo-characters, similar to normal individuals (Law, Weekes, Wong, & Chiu, this issue 2009).

More reliable evidence suggests that access to semantics in skilled reading of Chinese is constrained by both phonology and orthography operating

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interactively and that phonology has no inherently privileged role over orthography in driving semantic activation (Zhou & Marslen-Wilson, 1999a, 2000a, this issue 2009). For example, it has been shown in an eye movement tracking study that, while there is no evidence for early phonological activation in reading Chinese text containing orthographic errors, phonology helps readers recover from the disruptive effects of errors, as revealed by measures sensitive to the later-stage lexical processing (Feng, Miller, Shu, & Zhang, 2003). This suggestion is also supported by recent event-related potential (ERP) studies on the processing of orthographic and phonological information during sentence comprehension (Meng, Tian, Shu, Jian, & Zhou, 2008; Meng, Tian, Jian, & Zhou, 2007). Nevertheless, the controversy drags on (Ziegler, Tan, Perry, & Montant, 2000; but see Chen, Vaid, & Wu, this issue 2009), with evidence partly coming from studies using the Stroop interference paradigm (Guo, Peng, & Liu, 2005; Saalbach & Stern, 2004), which lacks ecological validity as a means of revealing the role of phonology in normal reading. Other studies switched to investigate lexical access in spoken word production (Wong & Chen, 2008, in press). Recent fMRI studies also investigated neural correlates of semantic and phonological processing (Booth et al., 2006; Xue et al., 2005, see Tan, Laird, Li, & Fox, 2005 for an early meta-analysis) and orthographic processing (Liu et al., 2008) during Chinese word recognition, with activations observed in the left inferior frontal cortex, the parietal lobule, the cingulate cortex and the fusiform gyrus. Furthermore, some related issues that were investigated include the role of the left fusiform gyrus in learning Chinese characters (Deng, Booth, Chou, Ding, & Peng, 2008; Dong et al., 2008; Xue, Chen, Jin, & Dong, 2006) and the neural differentiation between nouns and verbs (Li, Jin, & Tan, 2004; Tsai et al., 2009) and between concrete and abstract words (Zhang, Guo, Ding, & Wang, 2006).

Sublexical processing of phonetic and semantic radicals

Most Chinese characters are composed of semantic and phonetic radicals and the sublexical processing of these radicals plays an important role in the recognition of whole characters (Tsang & Chen, this issue 2009). Semantic radicals provide clues to the semantic category of whole characters. Phonetic radicals, which are usually meaningful characters by themselves, provide clues to the pronunciations of whole characters (i.e., encoding phonological information at the sub-character level). However, due to the evolution of the writing system, both functions are not complete, with only about one third of complex characters having the same pronunciations as their phonetic radicals. Earlier studies in 1980s demonstrated that both regularity (i.e., whether the whole character is pronounced the same as its phonetic radical) and consistency (i.e., whether a set of characters having the same phonetic

radical are pronounced the same) influence phonological activation and the naming speed of these characters (Fang, Horng, & Tzeng, 1986). Zhou and Marslen-Wilson (1999a) demonstrated further that regularity and consistency affect the role of phonological activation in constraining semantic activation of the whole characters. Regularity and consistency of sub-lexical phonological encoding continue to be topics of research in the last ten years. For example, recent ERP studies observed the phonetic consistency effect on N170 and P200 (Hsu, Tsai, Lee, & Tzeng, 2009) and gender differences in using sub-lexical phonological information (Hsiao & Shillcock, 2005; Hsiao, Shillcock, & Lee, 2007). Moreover, consistent with previous behavioural studies (Zhou & Marslen-Wilson, 1999b), it has been reported that the semantic information of the embedded phonetic radical is activated, as revealed in the ERP responses between 50 to 100 ms after perceiving a complex character (Lee, Tsai, Huang, Hung, & Tzeng, 2006) and that at least for low-frequency words, the phonological representation of the phonetic radical can be automatically activated, as reflected by the higher activation in the bilateral fusiform gyri, the posterior superior temporal gyrus and inferior parietal regions (Peng et al., 2004).

correspond roughly to nouns and verbs respectively in word category. In many European languages, word category is indicated by affix and can be detected about 150 ms after affix-onset (e.g., Friederici, Pfeifer, & Hahne, 1993; Hagoort, Wassenaar, & Brown, 2003; Neville, Nicol, Barss, Forster, & Garrett, 1991). In Chinese, however, a primary question is whether and when the category of an incoming word can be identified, given that this language lacks explicit means to indicate category information. In their recent ERP studies, Zhou and colleagues (Jiang & Zhou, 2009; Ye, Luo, Friederici, & Zhou, 2006) investigated this issue in syntactic structures with different complexity. They found that Chinese comprehenders could detect violations of word category about 50 ms after word-onset when listening to simple structures, and about 350 ms after word-onset when reading complex structures. The processing of word category in Chinese, as in some European languages, is reflected as an anterior negativity in ERPs. However, different from these European languages, the anterior negativity in Chinese is not followed by a P600, which is associated with syntactic reanalysis (e.g., Friederici, Hahne, & Mecklinger, 1996; Hahne & Friederici, 1999). Instead, the early negativity is accompanied by a later N400 effect, which is more likely to reflect difficulties of semantic integration. These results suggest that the processing of word category may be universal itself, but the consequence of the failed phrase construction seems to be language-specific. On the other hand, it was found that the Broca's area in the brain plays a role in processing the violation of word category during Chinese sentence reading (Wang et al., 2008) and the acquisition of a specific word category, the classifier, may have profound cognitive consequences on mental representation, thought and online sentence comprehension (Gao & Malt, this issue 2009; Jiang, Tan, & Zhou, 2009; Saalbach & Imai, 2007).

Grammatical relations

To establish grammatical relations between arguments, readers may use linguistic information such as word order and grammatical agreement. In

of English aphasic patients when reading subject-initial and object-initial sentences. Aphasic patients of both languages tended to interpret an ambiguous first argument as subject and consequently, performed better for subject- than object-initial sentences.

On the other hand, Chinese comprehenders may employ language-specific processes to parse grammatical agreement. Jiang et al. (2009) investigated temporal neural dynamics of binding noun phrases and the universal quantifier *dou* (all, every), which denotes that the properties being described are true for every member in a set of objects. They observed that a sustained positivity is elicited between 400 and 1100 ms on the universal quantifier which does not match the number of objects indicated by the preceding noun phrase. Moreover, Zhang and Zhang (2008) investigated the processing of aspect markers which are used to indicate whether an event is looked at from an outside or inside perspective (e.g., the perfective markers *le* and *yijing*, the imperfective markers *zhe* and *zhengzai*). They found that a left posterior negativity is elicited between 200 and 400 ms if disagreements appeared between aspect markers (e.g., the perfective marker *le* co-occurring with the imperfective marker *zhengzai*). In both cases, the ERPs in response to grammatical mismatches in Chinese are different from the left anterior negativity observed for tense, gender, or number disagreement in some European languages (Coulson, King, & Kutas, 1998; De Vincenzi et al., 2003; Deutsch & Bentin, 2001; Gunter, Friederici, & Schriefers, 2000; Gunter, Stowe, & Mulder, 1997; Newman, Ullman, Pancheva, Waligura, & Neville, 2007).

Thematic assignment

At the second stage of sentence comprehension, the processing system may consider lexical properties such as animacy to establish a relationship between thematic roles (who-did-what-to-whom). Animacy distinctions between arguments facilitate the comprehension of sentences with non-canonical word order (Caramazza & Zurif, 1976; Chen, West, Waters, & Caplan, 2006; Traxler, Morris, & Seely, 2002). But the impact of animacy has been shown to be language-specific rather than universal. In English (Weckerly & Kutas, 1999), which prefers a subject-initial order, the processing system tends to assign the first argument as actor and expects it to be animate. A mismatch between the animacy and the expected thematic role (e.g., when the first argument is inanimate) immediately gives rise to an

the first argument. As a consequence, the animacy information has no impact on the processing of the first argument.

Chinese can be seen as more like English than German in that it prefers the subject-initial order and does not have morphological case marking. However, in their recent study, Philipp, Bornkessel-Schlesewsky, Bisang, and Schlesewsky (2008) found no effect of animacy on the first argument but an N400 effect on a later position where it became obvious that the first inanimate argument was the actor. In other words, here the ERP patterns in Chinese mirrored those in German rather than those in English, suggesting that the animacy information does not initially influence the thematic interpretation but later on it plays an important role when two (or more) arguments must be integrated to establish a coherent relationship between thematic roles.

Is syntax prior to semantics?

A central question in the study of sentence processing is the relationship between syntactic and semantic processes. Two main classes of psycholinguistic models have been proposed to account for behavioural results, namely syntax-first models and interactive models. Syntax-first models (Fodor, 1983; Frazier & Fodor, 1978) assume that syntactic processes temporally and functionally precede semantic processes, while interactive models (Bates & MacWhinney, 1987; MacDonald, Pearlmutter, & Seidenberg, 1994; Marslen-Wilson & Tyler, 1980; Taraban & McClelland, 1998) assume that syntactic and semantic processes already interact at an early stage. Syntax-first models seem to be better supported by a series of ERP studies in English and German (Friederici, 2002). Friederici and colleagues found that the building of phrase structure takes place between 100 and 300 ms (e.g., Friederici et al., 1993, 1996; Hahne & Friederici, 1999; Neville et al., 1991), earlier than lexical access and semantic integration which show up between 300 and 500 ms (e.g., Chwilla, Brown, & Hagoort, 1995; Holcomb & Neville, 1991; Kutas & Hillyard, 1980; McCallum, Farmer, & Pocick, 1984; Van Petten, 1993). Moreover, semantic integration could be blocked when initial syntactic processing processes fail (Hahne & Friederici, 2002). However, the priority of syntactic processes is only partially supported in Chinese.

Consistent with studies in English and German, ERP studies in Chinese found that syntactic processes start earlier than semantic processes (Ye et al., 2006; but see Yang, Wang, Chen, & Rayner, in press, for inconsistent evidence from Chinese readers' eye movements). These two types of linguistic processes are independent from each other in an early stage (between 150 and 250 ms) but interact in a later stage (between 250 and 400 ms). But semantic processes would not be blocked when syntactic processes fail. Combined syntactic-semantic violations elicit an N400 effect which is similar or even larger than that elicited by pure semantic violations (Ye et al., 2006; Yu &

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Zhang, 2008), indicating that the processing system is dealing with difficulties in semantic integration.

Syntactic ambiguity

Psycholinguistic models also diverge on how many representations are constructed and maintained during the incremental processing of ambiguous sentences. Serial parsing models (e.g., Frazier, 1987) assume that only the structurally simplest analysis is maintained if a structure has more than one interpretation. If the new input does not support the preferred interpretation, the processing system will conduct reanalysis to reach the complex alternative. In contrast, parallel parsing models (e.g., McRae, Spivey-Knowlton, & Tanenhaus, 1998; Spivey & Tanenhaus, 1998; Tyler & Marslen-Wilson, 1977) assume that all syntactic alternatives are activated, competing for selection as the final interpretation. Although the processing of syntactic ambiguity is extensively examined in English (e.g., Altmann, 1998; Bornkessel, Fiebach, & Friederici, 2004; Mason, Just, Keller, & Carpenter, 2003; Novais-Santos, Gee, Shah, Troiani, Work, & Grossman, 2007), it has been rarely explored in Chinese. Using a syntactically ambiguous construction, Hsieh, Boland, Zhang, and Yan (this issue 2009) found Chinese readers maintain two candidate interpretations during online processing. They do not conduct reanalysis to get the more complex interpretation when the new input is inconsistent with the simpler one. In other words, this finding is in line with parallel parsing models.

DISCOURSE PROCESSING

Semantic and referential processes beyond sentences

Sometimes readers not only need to integrate a word with sentential context, but also need to integrate it with background information at a discourse level. In this integrative process, different types of information, such as discourse focus (whether the discourse structure foregrounds a particular protagonist), pragmatic inference and type of anaphoric expression, may come into play (Marslen-Wilson, Tyler, & Koster, 1993). For example, when encountering the word 'hamburger' in a sentence 'Mary ordered a hamburger', readers need to reactivate the related information (e.g., Mary was described as a vegetarian) provided by preceding sentences to see whether the incoming word is consistent with discourse context. Similar to English readers (e.g., Albrecht & O'Brien, 1993; Cook & Myers, 2004; Ehrlich & Rayner, 1983; O'Brien, Shank, Myers, & Rayner, 1988), Chinese readers showed longer first-pass reading time when the incoming word fitted well with the sentential context but not with the discourse context, indicating

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radical are pronounced the same) influence phonological activation and the naming speed of these characters (Fang, Horng, & Tzeng, 1986). Zhou and Marslen-Wilson (1999a) demonstrated further that regularity and consistency affect the role of phonological activation in constraining semantic activation of the whole characters. Regularity and consistency of sub-lexical phonological encoding continue to be topics of research in the last ten years. For example, recent ERP studies observed the phonetic consistency effect on N170 and P200 (Hsu, Tsai, Lee, & Tzeng, 2009) and gender differences in using sub-lexical phonological information (Hsiao & Shillcock, 2005; Hsiao, Shillcock, & Lee, 2007). Moreover, consistent with previous behavioural studies (Zhou & Marslen-Wilson, 1999b), it has been reported that the semantic information of the embedded phonetic radical is activated, as revealed in the ERP responses between 50 to 100 ms after perceiving a complex character (Lee, Tsai, Huang, Hung, & Tzeng, 2006) and that at least for low-frequency words, the phonological representation of the phonetic radical can be automatically activated, as reflected by the higher activation in the bilateral fusiform gyri, the posterior superior temporal gyrus and inferior parietal regions (Peng et al., 2004).