International Journal of Psychophysiology 84 (2012) 240–245

Contents lists available at SciVerse ScienceDirect

International Journal of Psychophysiology

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

Neural evidence for direct meaning access from orthography in Chinese word reading

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ARTICLE INFO

Article history:
Received 5 July 2011
Received in revised form 12 February 2012
Accepted 28 February 2012
Available online 14 March 2012

Keywords:
Word reading
Semantics
Chinese
Inferior frontal cortex
fMRI

ABSTRACT

A fundamental issue in the study of reading is to understand the processes involved in determining word meaning from print. We used functional magnetic resonance imaging (fMRI) and scanned participants performing lexical decision tasks to discriminate between real Chinese words and non-words, presented either visually or auditorily. For the visual task, two left inferior frontal cortical regions were significantly more activated for non-words than for words, one in BA (Brodmann's area) 44/45 implied in phonological processing, and one in BA47 implied in semantic processing. For the auditory task, stronger neural activity for non-words, relative to words, was only found in BA44/45 but not in BA47. The results were interpreted to suggest that printed words in Chinese can directly activate their semantic representations, independent of an indirect, mediated pathway through phonology. In reference to related imaging studies on English, our finding implies a greater reliance on orthography in Chinese reading.

1. Introduction

In learning to read, children may follow a mediated pathway to first sound out a word, either overtly or covertly, and then to obtain meaning from phonology. Skilled reading in adults, however, is so automatic and efficient that it seems to require a very different mechanism — a direct access pathway where printed words activate their associated semantic representations bypassing phonology (Baron and Strawson, 1976; Smith, 1973) (Fig. 1a). This viewpoint has had enormous impact on educators concerned with how reading should be taught in schools (Rayner and Pollatsek, 1989). It also constitutes a key assumption in current models of reading where the direct and the mediated pathways cooperate and jointly determine word meaning (Coltheart, 1978; Harm and Seidenberg, 2004; Perfetti et al., 2005). Research over the past three decades has substantiated the importance of phonological processing in visual word recognition for alphabetical languages, primarily for English in most studies (Frost, 1998; Van Orden et al., 1990). In contrast, unequivocal evidence that direct meaning access has a significant contribution in normal reading, over and above that from mediated access, is still lacking (Harm and Seidenberg, 2004).

This situation may be a reflection of the basic design feature of alphabetical writing systems in mapping letter strings to word sounds — any activation of orthographic representations will rapidly spread to phonological representations, making it difficult to dissociate the effects of orthography and phonology in meaning access. Categorically different from alphabetical languages, written Chinese is logographic with a weak orthography-to-phonology mapping (Chen and Shu, 2001), suggesting that the direct print-to-meaning pathway may be easier to demonstrate in the reading of Chinese. However, a long history of research has met with conflicting results, preventing the reaching of a consensus over this thesis. Some showed that meaning access from print is more manifest in Chinese than in English (Chen and Peng, 2001; Chen et al., 1995; Hoosain, 2002; Tzeng et al., 1977; Zhou and Marslen-Wilson, 2000), while others found that phonology plays a similar role in Chinese and English (Perfetti and Zhang, 1995; Tan and Perfetti, 1998).

Using functional magnetic resonance imaging (fMRI) techniques, we conducted a brain imaging study on Chinese addressing this long-standing debate. We noted that an underlying assumption in research on the topic of phonologically-mediated semantic access is that auditory word recognition and visual word recognition involve the same or at least highly overlapping phonological and semantic representations. The mediated pathway is developed by establishing connections between orthographic representations and existing phonological representations, and by making use of existing connections between phonology and semantics. Therefore, examination of how these two representations are accessed similarly or differently under auditory or visual word recognition tasks may help to inform lexical access in each modality alone, in particular in the visual modality for the present study.

We asked Chinese college students to perform the same lexical decision tasks over the same set of linguistics materials, presented either visually or auditorily. They would be presented with lists of items inside a scanner and asked to judge whether each item was a word or a non-word. This lexical decision task is a standard paradigm in word

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doi:10.1016/j.ijpsycho.2012.02.013

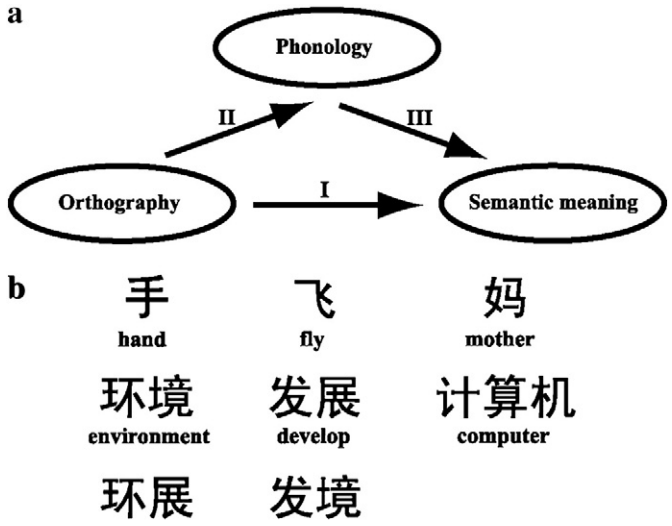

Fig. 1. Processing pathways in reading including a direct orthography to meaning pathway (I) and a mediated orthography first to phonology (II) and then to semantics pathway (III). b) Block characters as basic units of written Chinese. The top and the middle row show single-character and multiple-character words respectively, with their English translation below. The bottom row shows two examples of non-words used, constructed by re-combining characters of the first two real words shown in the middle row.

recognition research (Coltheart, 1978). A number of imaging studies in English with this task have consistently identified greater brain activity in left inferior frontal gyrus for non-word reading than for word reading (Binder et al., 2003; Gabrieli et al., 1998; Jobard et al., 2003; Mechelli et al., 2003). Such enhanced activations are generally attributed to elongated processing during non-word judgment relative to word judgment (Binder et al., 2003; Fiez, 1997; Price et al., 1996), and consequently informing the representations and processes involved in the lexical decision task. The words we used consisted of two single characters and represent the most common type of vocabulary in modern Chinese (Fig. 1b). Non-words were constructed by combining the first and the second character from two individual words (Fig. 1b) and thus matched with the words completely in perceptual properties. The visual and the auditory tasks employed two groups of participants and were identical otherwise except that the stimuli were present visually in one case but auditorily in the other.

As reported in Xiao et al. (2005), the central finding of the auditory task was that the non-words elicited stronger neural activity in BA (Brodmann's area) 44/45 in left inferior frontal gyrus, compared with words. A meta-analysis that extensively reviewed imaging research on language processing in English has shown that the BA44/45 is primarily engaged in phonological processing while a more anterior region, BA47 is engaged in semantic processing (Bookheimer, 2002). This conclusion had also been found applicable to Chinese in an earlier study of ours (Zhang et al., 2004). Therefore, in light of these literature findings, the result that auditory lexical decision on Chinese words activated only BA44/45 indicates that the task engaged phonological processing but not semantic processing. That is, it would be sufficient to decide whether or not a two-syllabic Chinese word was a real word based on its sound.

New to the present study were the visual task results and how they would compare with that from the auditory task. We envisioned three possibilities for different predictions on what would happen for the visual task.

By the triangular model in Fig. 1a, if processing of a visual word goes along the mediated pathway only, the phonological representation would always be activated before the semantic one. Once the phonological representation is activated, the situation would be similar to that in the auditory lexical decision task — participants may simply make their decisions based on the phonological information available and there is no need to rely on the semantic information that would not be available until after another stage of processing (i.e., from phonology to semantics). In this scenario, one would *not* expect activations in inferior frontal cortical regions involved in semantic processing, specifically BA47. This is the pattern that has been demonstrated for visual lexical decision tasks in English that routinely showed activation in BA 44/45 but not BA 47 (Binder et al., 2003; Jobard, et al., 2003; Mechelli et al., 2003; Fiebach et al., 2002).

On the other hand, if processing of a visual word just goes along the direct pathway, there would only be activations of the orthographic representation and subsequent activations of the semantic representation. One would expect to find activity in inferior frontal regions involved in semantic processing, i.e., BA47, assuming that participants base their judgments on semantic information but one would not expect to find activity in BA 44/45 for phonological processing as there would be no phonological activations.

There is a third possibility that processing of a visual word may go along the two pathways at the same time. If the phonological representation along the indirect pathway is activated before the semantic activations along the direct pathway, the situation would be similar to the first possibility described above, that is, participants could make use of the early-arriving phonological activations for lexical decision without further involving the late-arriving semantic activations. If the semantic representation is activated faster along the direct pathway from orthography than is the phonological representation along the indirect pathway, the situation would be similar to the second possibility described above, that is, participants would make use of the early-arriving semantic activations for lexical decision without involving the late-arriving phonological activations.

2. Methods

2.1. Participants

Twenty-eight college students (mean age 21.7 years, range 18–25 years, 13 female) from Shantou University (Shantou, China) participated in the study, half for the visual task and half for the auditory one. All were native Chinese speakers, strongly right-handed, with normal hearing, and normal or corrected-to-normal vision. Informed consent was obtained in accordance with guidelines from the Institute of Psychology, Chinese Academy of Sciences, Beijing, China.

2.2. Task and stimuli

The visual and the auditory sessions adopted exactly the same design with the same set of word/non-word items that included 120 words (mean frequency 79.88 per million) and 120 non-words. The non-words were constructed by randomly recombining the first character of one word with the second character of another (as shown in Fig. 1b) to produce two-character combinations that were not present in the Chinese vocabulary. With each category, half of the items (60) were used for the odd-numbered participants and the other half for the even-numbered ones. In each of the two sets of 60 items used for each participant, 12 were used for task familiarization and practice (both inside and outside the scanner) and 48 for testing; no item was used more than once. Each participant completed 96 test trials in total, half with real words and half with non-words.

Many Chinese characters contain a phonological radical that cues the pronunciation of the character. It is possible that such phonologically transparent characters may be processed differently from those characters that do not have a sound-cuing phonological radical (Lee et al., 2004). Here we used high frequency words usually consisting of high frequency characters that tend to have non-informative phonological radicals. Out of the 227 unique characters used, there were only 13 that sound the same as their phonological radical and 10 that sound the same as their phonological radical but with a different tone.