Sublexical Processing in Reading Chinese: A Development Study

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Three primed naming experiments were conducted to investigate the development of sublexical processing in reading Chinese. Target characters were either homophonic to (Experiments 1 and 2) or semantically related to (Experiment 3) phonetic radicals embedded in irregular complex characters, but not to the complex character themselves. For both the third and sixth grade school children, targets were named faster when they were preceded by such complex characters than by unrelated primes, although the semantic effect of complex characters was not signi cant for the third grade children. It is argued that, from early on in learning to read Chinese, phonetic radicals embedded in complex characters areed

morphemes corresponding to whole characters, phonetic radicals have the function of pointing to the pronunciations of whole characters. However, due to the evolution of the writing system, many such characters are no longer pronounced in the same way as their phonetic radicals. Previous studies (Hue, 1992; Peng, Yang, & Chen, 1994; Seidenberg, 1985) have found that the ''regularity'' of phonetic radicals in encoding phonological information for whole characters influences phonological processing of these characters, at least when they are of low frequency. Regular complex characters, which are pronounced in the same way as their phonetic radicals, are named faster than frequency-matched simple characters, which have no phonetic radicals, or irregular complex characters, which have different pronunciations from their phonetic radicals. These findings are often interpreted as suggesting that phonetic radicals embedded in complex characters are decomposed from visual input and mapped onto their own phonological representations as well as representations of other characters containing these radicals. The co-operative and competitive interaction between phonological processing of whole characters and their phonetic radicals leads to the ''regularity'' and ''consistency'' effect in naming complex characters (Seidenberg, 1985; Zhou & Marslen-Wilson, 1999a). Thus,

THE STRUCTURE OF CHINESE CHARACTERS AND SUBLEXICAL PROCESSING OF PHONETIC RADICALS

The Chinese writing system is often described as logographic or morphosyllabic, where the basic orthographic units, the characters, correspond directly to morphemic meanings and syllables. With some exceptions, each character in isolation represents one morpheme and has one pronunciation, although different characters may have the same pronunciations. Modern Chinese characters can be broadly differentiated into two categories (Li, 1993); simple and complex,[1] both of which are composed of strokes and arranged in squares of similar size. Simple characters (e.g., 土

青 qing[1], *blue*) that have exactly the same pronunciations as their phonetic radicals (Fan, Gao, & Ao, 1984; Li & Kang, 1993)

洇 *oil*; which contained

the phonetic radical 由 you[2], *cause*), although the latter were not named faster than irregular-inconsistent characters (e.g., 抽 chou[1], *lash*). Subsequent studies using similar designs, however, found both regularity and consistency effects for low frequency complex characters (Hue, 1992; Peng et al., 1994).[3]

The effect of sublexical phonological processing and its interaction with the frequency of comple

67495f715[5e)5r[(e)]TJ100113839g5515[(e)ee0014(Tm[(d

comee]TJ10012631553Tm[(c)23(h)23(a)46(r)23(a)5159123[(e)m[(e)23(fe1)63

proces8125eep058[ewef10

phon124325equeeweeahar]TJ10011[(fa)4(l)524(p)[(e)]TJ10013161

ee effe

participants to name complex characters and recorded their naming latencies. They found that both the third and sixth grade school children showed the consistency effect (as de□ned in Fang et al., 1986) but only the third grade, not the sixth grade children showed regularity effect. The latter result was probably due to the selection of stimuli. Shu and Wu (1996) used the same design and task as Yang and Peng (1997) and found that both the fourth and sixth grade children showed regularity and consistency effects while the third grade children showed nr

	[illegible]	海	低	美
Pinyin	mei(3)	hai(3)	di(1)	mei(3)
Gloss	*every*	*sea*	*low*	*beautiful*
Frequency	873	270	270	548
Stroke	6.1	9.3	8.8	8.4

Homophone primes are characters embedded in irregular complex primes as phonetic radicals. ''Frequency'' refers to average frequency of primes or targets (per million). ''Stroke'' refers to average number of strokes of primes or targets (per character).

phonological representations, the activation of these representations in the lexicon should facilitate the processing of targets, which share phonological properties with the radicals. The reason for using irregular rather than regular complex characters as primes was to make sure that any priming effects were from sublexical or subcharacter processing of phonetic radicals, rather than from lexical level processing of whole characters. It would be impossible to determine the source of facilitation in naming if targets were homophonic to both the whole characters and their phonetic radicals. The same design and stimuli were applied to both the third and sixth grade children.

In this and other experiments, we tested school children of the third and sixth grades. By the third grade, children should have learned large numbers of simple and complex characters (Shu et al., 1998) and have sufficient knowledge about the structure of complex characters and the function of their phonetic and semantic radicals (e.g., Shu et al., in press). Moreover, they can follow instructions to carry out the on-line experimental naming task (Zhou, Wu, & Shu, 1998). The sixth grade children clearly show advantages over lower grade children in their lexical processing. Indeed the pattern of their phonological and semantic processing is very similar to that of skilled adult readers (Zhou et al., 1998), with equally the third grade children. All the phonetic radicals embedded in complex primes were real characters on their own and they were also presented alone as homophone primes. Targets were chosen to be homophonic to the radicals but not to the complex primes. Targets had no orthographic or semantic relations with either complex primes or homophone (or radical) primes.

Another thirty irregular complex characters with left-right structure were also chosen as control primes. There were no orthographic, phonological, or semantic relations between control primes and targets at either lexical or sublexical level. Because our main interest was in phonological priming of phonetic radicals contained in complex primes, control primes were matched in fequency, visual complexity (in terms of the number of strokes), and orthographic structure (left-right composition of phonetic and semantic radicals) with the complex primes, rather than with homophone primes. Since there were no frequency counts for characters used by school children in different grades, the frequency information in Table 1 came from a corpus study of 1.8 million Chinese characters (Institute of Language Teaching and Research, 1986). The familiarity of characters for children was closely correlated to the usage of characters in print (Shu et al., 1998).

Besides the critical stimuli, the experiment also included 50 pairs of filler characters to discourage participants from using potential response strategies. Primes and targets in filler pairs were neither semantically nor orthographically nor phonologically related. Characters used as fillers were of various orthographic structures and with various frequencies. They, and their corresponding phonological forms (i.e., syllables), were not used in the critical stimuli. There were also 20 pairs of practice items, with similar composition as the formal stimuli.

A Latin square design was used to assign the critical primes and their targets into three counter-balanced test versions. In each version, the same targets appeared only once and one third of the targets were preceded by one of the three types of primes. The same filler prime-target pairs were used in the three test versions. A pseudo-random ordering was used to arrange the stimuli in each version, so that, across the test versions, the primes and targets from the same quintets of critical stimuli appeared at the same position in the testing sequence. The SOA between primes and targets was set at 100 ms. At this SOA, school children are capable of producing significant phonological, orthographically, or semantically based priming effects in naming (Wu, 1998; Zhou et al., 1998).

Procedure. The preparation of stimuli was as follows. All primes and targets (in 48 × 48 *songti* font) were generated by a computer program and stored as individual image files on a hard disk. A character was about

2.4 × 1.6 cm in size. The presentation of stimuli to participants and recording of reaction times were controlled by the dual-screen version software DMASTR, made available to us by Ken Forster. In each trial, an eye fixation signal (''+ '') was first presented at the centre of a computer screen for 300 ms, followed by a 300 ms blank interval. A prime was then presented for 100 ms and overwritten immediately by the corresponding target, which was presented for 400 ms. There was a 3-second interval between the disappearance of the last target and the appearance of the next eye fixation point. Participants were tested individually. They were seated about 60 cm from the screen and were asked to read into a microphone as quickly and as accurately as possible the second character of each trial. The microphone was interfaced with the computer to record voice onset latencies. Participants' performance was monitored by an experimenter and naming errors were recorded by hand in pre-printed scoring sheets.

Each participant saw first a list of 20 prime-target practice items. There was a break after practice. The first three pairs after the break were fillers. The complete test session for each participant lasted less than 15 minutes.

Participants. A total of 82 participants were tested, 39 from the third grade and 43 from the sixth grade. All participants were native speakers of Mandarine Chinese and were school children at the Affiliated School of Beijing Normal University.

Results

Nine participants at the third grade were excluded from analyses because of their high (over 20%) response errors. Three targets were also deleted for the third grade children because over half of participants in one or more test versions made mistakes in response. Mean naming latencies, based on correct responses, were then computed for each

phonological information can produce strong facilitatory effects in naming. What is most interesting in this experiment, however, is the finding that irregular complex primes were capable of facilitating the processing of targets that were homophonic not to the primes but to the phonetic radicals embedded in these primes. This sublexical phonological priming effect appeared only for the third grade children, not for the sixth grade children.

The significant priming effect for complex primes demonstrated that in reading complex primes, school children, like skilled readers, decompose the characters having the same phonetic radicals. All the phonetic radicals (embedded in complex primes and also presented in isolation as homophone primes) and all the targets were the same as those used in Experiment 1. A few control primes were also replaced to match with the new complex primes in frequency and visual complexity. The average frequency of complex primes and the average frequency control primes were both 129 per million. The average numbers of strokes were 10.0 and 9.9 per character respectively for the two types of primes. According to the ''Database of Chinese Characters Learned in School'', all the new primes had been taught to the sixth grade children.

Procedure. The preparation of stimuli and the test of participants were conducted in the same way as Experiment 1.

Participants. Thirty children of the sixth grade at Beijing Ji Jia Miao school were tested, 10 in each test version. All of them were native speakers of Mandarin Chinese.

Results

Mean naming latencies were computed on the bases of correct responses and they, together with error rates, are reported in the lower part of Table 2. One-way ANOVAs conducted for reaction times revealed a significant main effect of prime type [$F_1(2,58) = 9.31$, $P < .001$; $F_2(2,58) = 6.13$, $P < .01$]. Newman-Keuls tests showed that the mean reaction time for homophone (radical) primes was significantly faster than the time for control primes ($P < .01$). More importantly, the mean reaction time for complex primes was also faster than the time for control primes ($P < .1$ by participants and $P < .05$ by item). The difference between homophone and complex primes was not significant ($P > .1$). The analyses of error rates did not find significant results ($F_1 < 1$, $F_2 < 1$).

Discussion

The finding of a significant priming effect for irregular complex primes for the sixth grade children was consistent with the significant effect for the third grade children in Experiment 1. This effect demonstrated again that in reading complex characters children decompose the phonetic radicals from the whole characters and use them to access their own phonological representations, in parallel to the processing of whole characters. The presence of a significant effect for complex primes, contrasting with the absence of such an effect for the sixth grade children in Experiment 1, also demonstrated th(n)23(d)t

black)
that were semantically related to the phonetic radicals embedded in these primes (e.g., 白 bai[3], *white*) but not to the primes themselves were used as targets. If reading complex characters involves decomposing phonetic radicals and using them to access their own semantic representations, this sublexical semantic activation should be able to facilitate the processing of targets. Since decomposition and sublexical processing is likely to be

[4] Children tested in Experiment 1 were from a ''key'' school in Beijing while children tested in this experiment were from an ordinary school. It was possible that these children had different family backgrounds and there were general differences in educational standard between these schools.

modulated by frequency of complex characters, separate sets of complex primes were used here for the third and sixth grade children.

Method

Design and materials. The design and sample stimuli are presented in Table 3. A total of 60 irregular complex characters (e.g., 帕 pa[4], *handkerchief*) were used as complex primes, 30 each for the third and sixth grad

For the two groups of stimuli, a Latin square design was used to assign the critical primes and their corresponding targets into three counter-balanced test versions. Each version in each group had 30 critical targets, 10 of them preceded by one of the three types of primes. Another 50 pairs of characters that were neither semantically, phonologically, nor orthographically related were used as fillers and added to each test version. Characters and syllables used in the critical stimuli were not used again in fillers. A pseudo-random ordering was used to arrange the stimuli so that, across the three test versions in each group, the same targets appeared at the same positions. Twenty pairs of practice items were also used. The SOA between primes and targets was against set at 100 ms.

Procedure. The preparation of stimuli and test of participants were carried out in the same way as Experiments 1 and 2.

Participants. A total of 74 children at Beijing Ji Jia Miao school were tested, 39 from the third grade and 35 from the sixth grade. All of them were native speakers of Mandarin Chinese.

Results

Mean naming latencies and response error percentages are reported in Table 4. ANOVAs were conducted on reaction times, with prime type as a within-subject factor and grade as a between-subject factor. The main effect of grade was highly significant [$F_1(1,67) = 37.56$, $P < .001$, $F_2(1,27) = 260.09$, $P < .001$], indicating that the overall naming latency for the sixth grade children was much faster than the latency for the third grade children. More importantly, the main effect of prime type was significant [$F_1(2,134) = 8.55$, $P < .001$, $F_2(2,54) = 8.46$, $P < .001$]. Newman-Keuls tests showed that the overall naming latency for semantic primes was significantly faster than the latency for control primes ($P < .01$). The overall naming latency for complex primes was also significantly faster than the latency for controls ($P < .05$). The difference between semantic

TABLE 4
Experiment 3: Mean Naming Latencies (ms) and Error Percentages

Grade	*Semantic*

primes and complex primes was signi cant ($P < .05$). Moreover, the interaction between prime type and grade was not signi cant by participants ($F_1 < 1$), but it was marginally signi cant by items [$F_2(2,54) = 2.60$, $.05 < P < .1$]. Planned tests involving only complex and contro

in press). Moreover, sublexical phonological activation of phonetic radicals for these children semantic) radicals and lexical processing of simple and complex characters. The proposition treating sublexical processing of phonetic radicals in reading complex characters in the same way as using grapheme-phoneme correspondence in reading alphabetic words is clearly untenable. Lexical processing in reading complex characters is, after all, more analogous to lexical processing of semantically transparent compound words, where semantic properties of both whole words and their constituent morphemes are activated in parallel in reading (Sandra, 1990; Zhou & Marslen-Wilson, 1999b; Zwitserlood, 1994). Moreover, sublexical phonological and semantic processing of phonetic radicals embedded in complex characters has visual input and activating their corresponding phonological and semantic properties in the lexicon thus becomes not only natural but also mandatory. The parallel processing of whole characters and sublexical radicals appears not only in skilled reading, but also in the early stage of learning.

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