The temporal signatures of semantic and phonological activations for Chinese sublexical processing: An event-related potential study

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ABSTRACT

A large number of Chinese characters are made up by pairing a semantic radical and a phonetic radical. The phonetic radical usually gives a phonological clue for the pronunciation of the whole character but does not contribute to its meaning. Using an event-related potential (ERP) measurement, the present study was able to trace the very intricate interplay between phonological and semantic information embedded in the phonetic radical. It was found that, within the first 50 to 100 ms of perceiving the character, the semantic information of the phonetic radical was better preserved when the constituent phonetic radical provided a valid phonological clue (e.g., regular phonogram) than when it contained an invalid phonetic cue (e.g., irregular phonogram). However, no trace of semantic information from the phonetic radical was preserved after 300 ms. These ERP results detail the neuropsychological steps in reading Chinese and support the framework of the lexical constituent model.

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1. Introduction

A central question in psycholinguistic research concerns the types of information stored in the mental lexicon. Whatever theoretical perspective one takes, it is evident that the formal properties of words, such as how words sound or look, must be lexically represented. An issue still in debate is whether and how sublexical information might be represented in the mental lexicon. Among the studies examining this issue, the role of morphological structure has been most extensively studied in the visual domain. The accumulated evidence is far from conclusive.

In general, there are two theories of morphological processing. One is the semantic dependency hypothesis which proposes that complex words share lexical representations with their morphemic constituents only when there is a semantically transparent relationship between the complex words and their constituents (Marslen-Wilson et al., 1994). Semantic transparency is defined as whether a word has a transparent meaning relationship with its constituent words. For example, the meanings of semantically transparent words can be derived from the meanings of their constituents (e.g., milkman, cleaner). Words are semantically opaque if their meanings are unrelated to the meanings of their constituents (e.g., butterfly, corner). This hypothesis is supported by evidence from priming studies where the primes were semantically associated with the constituents of semantically transparent compounds (e.g., women-MILKMAN), semantically opaque
compounds (e.g., bread–BUTTERFLY), or pseudo-compounds (e.g., girl–BOYCOTT), which serve as targets. A facilitative semantic priming effect was found for the constituents of semantically transparent compounds, but no reliable semantic priming was found for the components of semantically opaque compounds and pseudo-compounds (Sandra, 1990; Zwitserlood, 1994).

An alternative hypothesis proposes that any input string comprised of a morphological surface structure may be subject to decomposition irrespective of semantic transparency (Taft and Forster, 1975). This hypothesis is supported by Longtin et al. (2003), who found that the recognition of French stems was accelerated significantly and equivalently by semantically transparent and opaque words. Rastle et al. (2004) investigated what information is used to segment a complex word into its morphemic constituents during visual word recognition and found that letter strings comprising a morphological surface (e.g., cleaner, corner), no matter whether they are semantically transparent or opaque words, activate sublexical morphemic units (e.g., clean, corn, -er). Their results suggest that there is a purely orthographic structural decomposition, which occurs in early visual word recognition independent of semantic transparency.

A fundamental difference in sublexical units is inherent between alphabetic (such as English) and non-alphabetic (such as Chinese) writing systems. In an alphabetic system, letters and words represent two distinct levels, where letters are constituent parts that are wholly contained within the word. In Chinese, approximately 80% of the characters are phonetic compounds that are made up of a semantic radical (usually on the left) and a phonetic radical (usually on the right). Very often, the same radical and phonetic radicals are stand-alone characters with their own pronunciations and meanings. In other words, the radicals are orthographic units that may have value as morphemes (unlike letters). To illustrate, the phonetic compound 木 (mu4, “wood”) and the phonetic radical 根 (feng1, “wind”) are simple characters with their own meanings and pronunciations. There is increasing evidence to indicate that reading a complex character involves the processing of its radicals. For example, Yeh and Li reported a repetition blindness effect for radicals (with no other intervening character) when the duration of exposure is less than 50 ms and suggested that sublexical processing occurred relatively early in Chinese character recognition (Yeh and Li, 2004). The repetition of the semantic radical facilitated target identification, especially when prime and target were formed by the same semantic radical and when the meaning of the semantic radical was consistent with the meaning of the whole prime character (Feldman and Siok, 1999). In addition, researchers have tried to describe how well the phonetic radical provides cues to the pronunciation of the whole character in terms of its regularity, which is defined as whether the complex character is pronounced in the same way as its phonetic radical. For example, 根 (feng1) is pronounced the same as its phonetic radical 根 and is defined as a regular character, whereas 根 (tsai1) is pronounced differently from its phonetic radical 网 (qing1) and is thus defined as an irregular character.

Previous studies have also demonstrated a frequency by regularity interaction in naming Chinese phonograms: the speed of naming a regular character is much faster than that of naming an irregular character, especially when those characters are low in frequency (Hue, 1992; Lee et al., 2005; Seidenberg, 1985). These findings suggest that semantic and phonetic radicals play different functions in compound phonomgrams. Semantic radicals usually indicate the semantic category of morphemes corresponding to the phonomgrams, whereas phonetic radicals provide the phonological clues for the whole characters.

Since many semantic and phonetic radicals can be characters, having both meaning and pronunciation, they may participate at the lexical level and the sublexical level in different ways, that is, as a word at the higher level and as a potential cue to meaning or pronunciation at the sublexical level (Perfetti et al., 2005). However, according to the semantic dependency hypothesis, even when phonetic radicals are legal characters with their own semantic representations at the lexical level, they do not activate the semantic representations when they serve as sublexical units of the phonomgrams since they have nothing to do with the meaning of the whole character (i.e., they are semantically opaque). Zhou and Marslen-Wilson (1999) found a facilitative priming effect when a target (e.g., 雨, “rain”) was semantically related to the phonetic radical (e.g., 根, “wind”) embedded in the prime (e.g., 根, “maple”), even though the prime itself was not semantically related to the target. This evidence of semantic activation of a phonetic radical in complex characters appeared to last at least 200 ms regardless of whether the prime was a regular or irregular character. This suggested that the sublexical processing of phonetic radicals is, like lexical-level processing, not only a phonological event but also a semantic event and, thus, that there are no fundamental differences between the sublexical processing of phonetic radicals and the lexical processing of simple and complex characters (Zhou and Marslen-Wilson, 1999).

A remaining question is how the dual processes, lexical and sublexical, interact with each other, especially for the phonetic radicals. Because the main function of a phonetic radical is to serve as a clue to the pronunciation of the whole character rather than its meaning, Perfetti et al. (2005) proposed an interactive constituency model for Chinese character reading. In this model, the representation of a word consists of three interlocking constituents: orthographic, phonological, and semantic. The input units are the radicals and the spatial relationship between the radicals. Successful lexical retrieval (word identification) requires full specification of all three constituents. According to this model, the validity of a phonetic radical (whether a character in which the phonetic radical appears has the same pronunciation as the radical does as a stand-alone character) affects the sublexical semantic activation. Unfortunately, Zhou and Marslen-Wilson’s study examined the sublexical semantic activation of regular and irregular characters in separate experiments, leaving this question unanswered.

The present study aims to further explore how and when phonetic radicals can be manifested via lexical/sublexical processing, along with providing phonological information. In order to probe this question, different prime types and
stimulus onset asynchronies (SOAs) were manipulated to replicate the sublexical semantic priming effect found by Zhou and Marslen-Wilson (1999). However, instead of using traditional reaction time measurements, we used event-related potentials (ERPs). The measurement of reaction time reflects the summation of all the steps that elapse prior to the behavioral response to a language task. In contrast, ERPs provide insight into the time course of language comprehension because they can provide data that reflect processing at each millisecond from the onset of the language stimuli. Most importantly, ERPs can reflect how cognitive operations are processed in the brain. For example, the N400 is a negative polarity ERP component that is maximal over centro-parietal electrode sites; it usually emerges at about 250 ms after the onset of word stimulation and reaches its maximal amplitude at around 400 ms. It is widely accepted that the N400 component elicited by words is particularly sensitive to the processing of semantics, both in prime–target word pairs (Kutas and Federmeier, 2000) and in sentential contexts (Kutas and Hillyard, 1980a; Kutas and Hillyard, 1980b). The amplitude of the N400 component is usually inversely related to the degree of fit between the word and its preceding semantic context. That is, the N400 amplitude is attenuated for words that are preceded by a semantically related word or semantically congruous context, compared to words that are preceded by an unprimed word or semantically incongruous context. Recent studies have also shown that indirectly related targets can elicit intermediate N400 amplitudes (Chwilla et al., 2000; Kiefer et al., 1998; Weisbrod et al., 1999).

In this study, whether the semantic properties associated with a phonetic radical embedded in the two types of phonograms (regular and irregular characters) are automatically activated will be indexed by the N400 component. Four types of prime–target relationships, including lexical and sublexical semantic associations, are manipulated (see Table 1, the prime–target relationship will be explained in more detail in the Experimental design and materials section). We expect that both the lexical and sublexical semantic activation can be captured by the manifestation of the N400 component. In addition, in order to trace the time course of sublexical semantic activation, different SOAs between the prime and the target (50 ms, 100 ms, and 300 ms) were manipulated as a between-subject variable. We expect that the sublexical semantic activation of a phonetic radical will fade away over time since the meaning of the phonetic radical is usually irrelevant to, or may eventually interfere with, the meaning of the character. In addition, Tan and Perfetti (1997) demonstrated that the naming time for a Chinese target character (e.g., 宽, “wide”) was facilitated by a prime (e.g., 包, “include”) that was homophonically related to a synonym of the target, as well as by the synonym itself (e.g., 包, “wide”). This is the so-called phonologically mediated priming effect. Since the main function of a phonetic radical is to provide a phonological clue to the whole character, its phonological information should persist. Thus, when the phonetic radical is embedded in a regular character prime, which has the same sound as the phonetic radical, it has a greater chance of retaining its meaning through phonological mediation (Tan and Perfetti, 1997), relative to when it is embedded in an irregular character prime. In other words, regular and irregular characters may have different time courses or strength for sublexical semantic activations.

### Table 1 – Experimental design, example character, and characteristics of stimuli for four priming conditions

<table>
<thead>
<tr>
<th>Prime types</th>
<th>Semantically related</th>
<th>Regular phonogram</th>
<th>Irregular phonogram</th>
<th>Unrelated control</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prime Pronunciation</td>
<td>夫</td>
<td>/fu1/</td>
<td>概</td>
<td>/du1/</td>
</tr>
<tr>
<td>Meaning</td>
<td>Husband</td>
<td>Maple</td>
<td>Read</td>
<td>Very</td>
</tr>
<tr>
<td>Mean frequency</td>
<td>843</td>
<td>938</td>
<td>912</td>
<td>1128</td>
</tr>
<tr>
<td>Mean subjective familiarity</td>
<td>5.02</td>
<td>5.03</td>
<td>5.24</td>
<td>5.28</td>
</tr>
<tr>
<td>Mean No. of stroke</td>
<td>12.53</td>
<td>14.00</td>
<td>11.02</td>
<td>11.84</td>
</tr>
<tr>
<td>Phonetic radical Pronunciation</td>
<td>風</td>
<td>/feng1/</td>
<td>雨</td>
<td>/mai4/</td>
</tr>
<tr>
<td>Meaning</td>
<td>Wind</td>
<td>Sell</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Target Pronunciation</td>
<td>妻</td>
<td>/qi1/</td>
<td>雨</td>
<td>/yu3/</td>
</tr>
<tr>
<td>Meaning</td>
<td>Wife</td>
<td>Rain</td>
<td>Buy</td>
<td>Vehicle</td>
</tr>
<tr>
<td>Mean frequency</td>
<td>1352</td>
<td>1372</td>
<td>1253</td>
<td>1363</td>
</tr>
<tr>
<td>Mean subjective familiarity</td>
<td>5.88</td>
<td>5.95</td>
<td>5.68</td>
<td>5.68</td>
</tr>
<tr>
<td>Mean No. of stroke</td>
<td>8.98</td>
<td>9.31</td>
<td>10.78</td>
<td>11.22</td>
</tr>
<tr>
<td>Mean semantic relatedness</td>
<td>6.62</td>
<td>6.53</td>
<td>6.73</td>
<td>1.37</td>
</tr>
</tbody>
</table>

2. Results

2.1. Behavioral data

On average, the participants correctly responded to 90% of the probe recognition task in the three SOA conditions (SOA50, mean 90%, range 80–98%; SOA100, mean 89%, range 82–97%; and SOA300, mean 90%, range 82–98%). These indicate that the
participants seemed to be reacting to the experimental stimuli appropriately during the recording sessions.

2.2. ERP data

The grand mean ERPs across the four prime types (SR, RP, IP, and UC) of the three SOAs are plotted in Figs. 1–3. These waveforms appear somewhat different at the three SOAs. This is due, in part, to the differential overlap of the prime and target ERPs, particularly in the SOA 50 ms and 100 ms conditions.

2.3. Mean amplitude of N400 analysis

The N400 component was used to examine the effect of semantic priming. For the standard N400 analysis, the mean amplitude of the N400 component was measured in the time window of 350–500 ms after the onset of the target for all three SOA experiments (Figs. 1–3, gray-shaded areas). For each analysis of variance (ANOVA) of this study, the Geisser–Greenhouse adjustment to the degrees of freedom was applied to correct for violations of sphericity associated with repeated measures. Accordingly, for all F tests with more than 1 degree of freedom in the numerator, the corrected p-value and degrees of freedom are reported. The effects of SOA manipulation (SOA50, SOA100, and SOA300), the prime types (SR, RP, IP, and UC), and the location of the recording sites (F3, FZ, F4, C3, CZ, C4, P3, PZ, and P4) were examined via the mean amplitude of N400 in a mixed-design three-way ANOVA. The data showed a significant three-way interaction among SOA, prime type, and electrode site (F(13.6,494.7)=2.734, p=0.004). Due to the differential overlapping brainwaves elicited by the prime and the target which would make direct comparisons of the individual conditions as a function of SOA very difficult to interpret, the post hoc analysis aimed to examine the effect of prime types and their interaction with the location of the recording sites for each SOA condition.

In the SOA50, the data showed significant main effects of prime type (F(2,8,70.5)=6.305, p=0.001) and a significant interaction between prime type and electrode site (F(6.2,154.9)=6.208, p=0.000). The simple main effect showed that the effect of prime type was significant at C3, CZ, C4, P3, PZ, and P4 (all p<0.01). The post hoc comparisons revealed that the UC condition elicited a larger N400 component than the SR, RP, and IP conditions (all p<0.05). However, the SR, RP, and IP conditions did not significantly differ from each other. This kind of pattern was prominent at the C4 and P4 sites, which is congruent with the well-defined geometrical pattern of N400 for semantic processing. These effects are the classical semantic priming effects, reflecting processes related to linguistic analysis that depend on the degree of semantic association between the prime and the target characters. The N400 effect did not differ among the SR, RP, and IP conditions, suggesting that the semantic property of the phonetic radical was activated at the level of lexical processing.

In the SOA100, the data showed significant main effects of prime type (F(2,4,59.2)=18.59, p=0.000) and a significant interaction between prime type and electrode site (F(4.9,123)=3.465, p=0.006). The simple main effect showed that the effect of prime type was significant in all the electrode sites (all

Fig. 1 – The grand mean ERPs across four prime types (SR=semantically related condition, RP=regular phonogram condition, IP=irregular phonogram condition, UC=unrelated condition) of the SOA50 experiment. The gray-shaded area indicates the time window of the N400 component.
The post hoc comparisons revealed that the UC condition elicited a larger N400 component than the SR and RP conditions at every electrode site (all \( p < 0.01 \)). However, the UC condition only showed greater negativity of N400 than the IP condition at Cz, Pz, and P4 (\( p < 0.01 \)). In addition, the IP conditions showed greater negativity in this time window relative to the SR condition at most of the electrode sites (F3, Fz, Cz, Pz, and C4, all \( p < 0.01 \); C3 and P4, all \( p < 0.05 \)), except for P3 and F4. The RP condition showed a higher N400 component than the SR condition at the F3, C3, CZ, C4, and PZ sites (all \( p < 0.05 \)). It seems that, when the prime was presented for 100 ms, the activated sublexical semantic information embedded in the phonetic radical began to fade away, especially for those irregular phonograms.

In the SOA300, the data showed significant main effects of prime type \( (F(2.7, 62.7) = 11.417, p = 0.000) \), and the interaction between prime type and electrode site only achieved marginal significance \( (F(3.9, 89.5) = 2.195, p = 0.07) \). The simple main effect showed that the effect of prime type was significant in all the electrode sites (all \( p < 0.01 \)). The post hoc comparisons revealed that the UC, RP, and IP conditions elicited larger negativities of the N400 component than the SR condition at every electrode (all \( p < 0.01 \)), whereas the UC, RP, and IP conditions did not significantly differ from each other. The data suggest that the activated sublexical semantic information embedded in the phonetic radical no longer exists after 300 ms.

### 2.4. Successive time window analysis

In order to track the time course of different types of semantic priming effects for each SOA, we conducted further analysis to compare the brain activity in successive 20 ms time periods. This approach also allowed for investigation of the onset time of significant lexical and sublexical semantic priming effects. In line with previous studies, the analysis of the mean amplitude of N400 from the three SOAs showed that the semantic priming effects were larger over the central and parietal sites in the midline and right hemisphere. Thus, we selected a subset of electrodes to represent this specific region (including CZ, CPZ, CZ2, and CPZ2) that showed the typical N400 effect of semantic processing for this analysis. Successive mean amplitudes for this subset of electrodes measured every 20 ms between 300 and 500 ms after target onset served as the dependent variables. The one way within-subjects ANOVAs for the effect of prime type (SR, RP, IP, and UC) were tested for each time window and each SOA. For each time window, the post hoc multiple comparisons for testing the lexical (UC–SR) and sublexical (UC–RP and UC–IP) semantic priming effects were conducted when the main effect of the prime type was significant (\( p < 0.01 \)). In addition, the only difference between the experiments was the SOA. In order to compare different types of semantic priming effects across three SOA experiments directly, the regional ANOVAs were also calculated for each pair of semantic priming subtraction waveforms (UC–SR, UC–RP, and UC–IP) by using the SOA (50 ms, 100 ms, and 300 ms) as a between-subjects variable. Due to the risk of false-positive effects in the multiple interrelated comparisons in these analyses, results were only considered significant if they persisted over at least two successive time periods with \( p < 0.01 \).

The results for the regional analyses over successive time periods in the three SOAs are shown in Table 2 and Fig. 4. They
reveal that different types of semantic priming show a similar scalp distribution but influence brain activity with different time courses in the three SOAs. Significant effects of lexical semantic priming (UC–SR) started later for the target in the SOA50 (400 ms) when compared with the SOA100 and SOA300 conditions (340 ms). The sublexical semantic priming effects (UC–RP and UC–IP) only appeared in SOA50 and SOA100 conditions. Furthermore, the priming effect of UC–RP started earlier and showed a longer period of significance than the priming effect of UC–IP in both the SOA50 and SOA100.

Direct across SOAs comparisons of the subtraction waveforms confirmed the previous findings. In general, significant main effects of the SOA appeared from 360 to 440 ms after the onset of target (all F > 4.5, p < 0.01). For the priming effect of the UC–SR comparison, both the SOA100 and SOA300 conditions showed significantly earlier and greater semantic priming effects than the SOA50 condition from 340 to 400 ms. Moreover, the SOA50 condition showed a greater priming effect of UC–SR than the SOA100 and SOA300 conditions from 400 to 440 ms.

### Table 2 - The significance of different types of semantic priming effects in the three SOA experiments over successive time periods that cover the typical N400 window

<table>
<thead>
<tr>
<th>Epoch (ms)</th>
<th>SOA50</th>
<th>SOA100</th>
<th>SOA300</th>
</tr>
</thead>
<tbody>
<tr>
<td>300–320</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>320–340</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>340–360</td>
<td></td>
<td></td>
<td>**</td>
</tr>
<tr>
<td>360–380</td>
<td></td>
<td></td>
<td>**</td>
</tr>
<tr>
<td>380–400</td>
<td>**</td>
<td>**</td>
<td>*</td>
</tr>
<tr>
<td>400–420</td>
<td>**</td>
<td>**</td>
<td>*</td>
</tr>
<tr>
<td>420–440</td>
<td>**</td>
<td>**</td>
<td>*</td>
</tr>
<tr>
<td>440–460</td>
<td>**</td>
<td>**</td>
<td>*</td>
</tr>
<tr>
<td>460–480</td>
<td>*</td>
<td>**</td>
<td>*</td>
</tr>
<tr>
<td>480–500</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note: The time epochs are measured from target onset.

* p < 0.05.

** p < 0.01.
For the priming effect of UC–RP comparison, the SOA50 condition showed a greater sublexical semantic priming effect than the SOA100 condition between 380 and 400 ms. Furthermore, both the SOA50 and SOA100 conditions showed a greater priming effect of UC–RP than the SOA300 condition from 420 to 460 ms. A similar pattern was found in the UC–IP priming effect. The SOA50 condition showed a greater sublexical semantic priming effect than the SOA100 and SOA300 conditions between 380 and 400 ms. In addition, both the SOA50 and SOA100 conditions showed greater priming effect of UC–IP than the SOA300 condition from 420 to 440 ms.

3. Discussion

The main purpose of this study was to examine whether there is sublexical semantic activation for phonetic radicals and how this process interacts with the function of the phonetic radical in providing phonological information for the whole phonogram. This was done by using the N400 ERP component as an index of semantic processing in order to examine the sublexical semantic priming effect for both regular and irregular phonograms. The results revealed a temporal sequence of sublexical semantic activation in relation to the phonetic radical representing the phonological clue. First of all, we observed a typical semantic priming effect of N400 for the primes (e.g., 半, pu1, “husband”) that were semantically related to the targets (e.g., 舌, che1, “wife”) across the three SOAs of 50 ms, 100 ms, and 300 ms. Second, when the prime was a regular phonogram (e.g., 風, feng1, “maple”) whose phonetic radical (e.g., 風, feng1, “wind”) was semantically related to the target (e.g., 雨, yu3, “rain”), significant N400 effects were found when the SOAs between the prime and the target were 50 ms and 100 ms, but the N400 effect disappeared at an SOA of 300 ms. Finally, when the prime was an irregular phonogram (e.g., 本, du2, “read”) whose phonetic radical (e.g., 母, mai4, “sell”) was semantically related to the target (e.g., 買, mai3, “buy”), a significant N400 effect could be found at the SOAs of 50 ms and 100 ms. However, this effect was significantly smaller at the SOA of 100 ms compared to that at 50 ms and totally disappeared at 300 ms. Furthermore, the regional analyses of difference wave over successive time periods revealed that, in both SOAs of the 50 ms and 100 ms conditions (see Table 2), the time periods showing significant sublexical semantic priming effects elicited by irregular

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Fig. 4 – The scalp distributions of the different types of semantic priming effects isolated by subtraction waveforms (UC–SR, UC–RP, and UC–IP) for the three SOA experiments, at successive 20 ms intervals between 340 and 500 ms after the onset of target. Different types of priming effects showed similar scalp distributions but with different onsets and durations across the three SOA experiments.
phonological and semantic representations. This model on their own, they will in turn connect to their corresponding radical. When these position-free radicals are legal characters are activated through a position-free representation of that position-specific radical representations and these, in turn, are position specific. A complex character is recognized via its phonology, and semantics. In the orthographic subsystem, and assumes that there are three subsystems: orthography, phonology, and semantics and a successful separability of orthography, phonology, and semantics in the early stage. Meanwhile, the mediation of the phonological system. The semantic activations from orthographic and phonological systems are consistent for regular characters, but less consistent for irregular characters, which makes the sublexical semantic activation of the phonetic radical last longer for regular characters than for irregular characters. However, this is not to claim that phonological mediation is obligatory, but to show that a pathway from phonology to meaning is possible.

On the other hand, the current findings are congruent with the lexical constituent model, which assumes that a word representation consists of the three interlocking constituents of orthography, phonology, and semantics and a successful lexical access needs the activation of all three constituents. According to this model, the input units are radicals and the semantic access needs the activation of the whole character. That phonetic radical of an IP character did not take longer to activate its semantic value than that of an RP character can be explained by the direct linkage between orthography and semantics, which allows for a rapid retrieval of meaning without phonological involvement. In other words, for both RP and IP characters, their phonetic radical can activate their meaning through the direct linkage between orthography and semantics in the early stage. Meanwhile, the connection between phonology and semantics provides the second route for the mediated access to the meaning. Thus, the phonetic radical of an IP character would receive stronger semantic activation due to the congruent phonological activation of phonetic radical and the whole character. The lexical constituency model thus can capture the regularity effect by representing the pronunciations of radicals that are part of the orthographic character level and connecting their output to phonological units and will explain how phonology interacts with the other constituents of word representation. The present findings of the automatic sublexical semantic activation and how this activation interacts with the phonetic validity are congruent with the prediction of the lexical constituency model for word identification.

In conclusion, precise meaning is extracted from a very brief viewing of a spelled word or a written character when reading, amid conflicting information embedded in the script. To accomplish this, a reader’s brain has to carry out complex neural synthesis in order to resolve the conflict. The present data used the N400 ERP component to demonstrate that the sublexical processing of phonetic radicals in reading Chinese involves activation of semantic properties corresponding to the radicals and the whole character. Readers pick up all the
Semantic information associated with both lexical and sub-lexical levels within 50 to 100 ms. Since the meanings of phonetic radicals are usually irrelevant to the meanings of the whole characters, readers will have to solve the conflict between these two levels. Our data showed that the sublexical semantic activation of phonetic radicals were modulated by the validity of the phonological information that the phonetic radical carries. However, none of the sublexical semantic information associated with the phonetic radical was preserved after 300 ms. These data reveal the temporal dynamics of the sublexical semantic and phonological processing and support the framework of the lexical constituent model, which reveals the direct linkages among the orthographic, phonological, and semantic lexicons in reading Chinese.

4. Experimental procedures

4.1. Participants

Seventy-six college students were paid US$16 for their participation: 26 (aged 20–26 years, mean 22.5 years) in the SOA50 condition, 26 (aged 21–28 years, mean 23.9 years) in the SOA100 condition, and 24 (aged 20–23 years, mean 23.3 years) in the SOA300 condition. All participants were native Chinese speakers with no history of neurological or psychiatric disorders. They either had normal or corrected-to-normal vision. Written consent was obtained from all participants. The research protocol was approved by the institutional review board of Academia Sinica. No students participated in more than one SOA condition.

4.2. Experimental design and materials

A total of 180 prime–target pairs was used for four types of priming conditions (45 pairs for each condition, see Table 1): (1) the semantically related condition (SR), where the target character is semantically related to the prime at the whole character level; (2) the regular phonogram condition (RP), where the prime characters are regular phonograms (their phonetic radicals are homophonous to the phonograms) and the targets were chosen to be semantically related to the phonetic radicals but not to the whole complex characters; (3) the irregular phonogram condition (IP), where the prime characters are irregular characters (their phonetic radicals are not homophonous to the phonograms) and the targets were chosen to be semantically related to the phonetic radicals but not to the whole complex characters; (4) the unrelated control condition (UC), where the target character is not semantically, orthographically, or phonologically related to the prime either at the whole character level or at the radical level. The UC serves as a baseline. The mean frequency, subjective familiarity, and number of strokes for prime and target were matched across these four conditions. The semantic relatedness was rated in a 7-point scale pretest, ranging from 1 (not related at all) to 7 (extremely related). The average point scores were above 6 for the semantic relatedness of prime (as a whole character) to target in the SR condition and for the semantic relatedness of the phonetic radical (of prime) to target in the RP and IP conditions. The average point scores were below 2 for the semantic relatedness of prime to target in the RP, IP, and UC conditions. The characteristics of primes and targets and the average semantic relatedness for the four conditions are listed in Table 1. The same set of stimuli was used in the three conditions with different SOAs (50 ms, 100 ms, and 300 ms).

4.3. Procedure

Participants were tested individually in an electrically and magnetically shielded room. They were seated about 60 cm away from the screen. Each participant saw a list of 20 prime–target trials for practice, and then saw 180 experimental trials in random order during 4 test sessions. Participants could take a break between test sessions for as long as they needed. Given a viewing distance of about 60 cm, each character encircled a visual angle of 1° in width and in height. The first two pairs that appeared after each break were always filler pairs, where the primes and targets were not semantically, orthographically, or phonologically related. In each trial, an eye fixation signal, “+”, was first presented at the center of the screen for 500 ms. A prime was then presented for 50 ms, 100 ms, or 300 ms, depending on the SOA condition, and was overwritten immediately by the corresponding target, which was presented for 500 ms, followed by an 800 ms blank interval. In order to avoid any overlap between ERP indices of semantic association (N400) and the more general decision-related responses such as the P300, we utilized a character recognition task, in which a probe was presented after the blank, and participants had to decide whether the probe was the first or the second character presented in that trial and press the left or right key of the mouse. Correctness and reaction time were recorded. The inter-trial interval was 2.5 s. Participants were instructed to blink if necessary during that time period. It took each participant around 20 min to complete the experiment.

4.4. ERP recording and data preprocessing

The electroencephalogram (EEG) was recorded from 64 sintered Ag/AgCl electrodes mounted on an electrode cap (QuickCap, Neuromedical Supplies, Sterling, USA) and referenced on-line to the left mastoid and re-referenced off-line to the average of the right and the left mastoids. The EEG was continuously recorded and digitized at a rate of 500 Hz. The signal was amplified by SYNAMPS® (Neuroscan, Inc.) amplifiers with the band-pass set at 0.1–100 Hz. Vertical eye movements were recorded by electrodes placed on the supra-and infraorbital ridges of the left eye, and horizontal eye movements by electrodes placed lateral to the outer canthi of the right and left eyes. Electrode impedances were kept below 5 kΩ.

For off-line analysis, the continuous wave was segmented into epochs, from 100 ms prior to the onset of the prime to 800 ms after target onset, and used the 100 ms pre-stimulus for baseline correction. Two stages of artifact rejection were performed. The first was the eye-blink rejection, where trials with voltage variations larger than 100 μV in either vertical or horizontal electro-oculography were rejected. In the second, trials with voltage variations larger than 50 μV in at least one
of the remaining channels were rejected. On average, 8% of the trials were rejected due to such artifacts. Data were band-pass filtered between 0.1 and 30 Hz. The average ERPs were computed for each subject, electrode, and priming condition in each SOA experiment.

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