Spread of Activation in the Mental Lexicon

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Abstract

Spread of activation and interaction between different types of knowledge representations in the mental lexicon were investigated in three semantically mediated phonological priming experiments, conducted on both English and Chinese. Facilitatory effects were found in naming not only for words (e.g., *boy*) that were semantically related to their primes (e.g., *girl*), but also for words that were homophonic to the semantic targets (e.g., *buoy*). The amount of priming varied according to whether homophone targets were also orthographically similar to semantic targets. An inhibitory priming effect was also found for words that were orthographically similar to but phonologically different from semantic targets. It is concluded that spread of activation between words sharing semantic properties is not encapsulated in the semantic system. The phonological and orthographic representations of words receiving spread of semantic activation are also automatically and immediately activated, even though they are not supported directly by sensory input.

Introduction

Two fundamental assumptions of interactive-activation based theories of language processing are the spread of activation and the interaction between different levels or different types of knowledge representations (e.g., Dell, 1986; Plaut, 1995; Plaut, McClelland, Seidenberg, & Patterson, 1996). In word recognition, the activation of one type of knowledge representation in the mental lexicon is assumed to spread automatically and continuously to other connected representations, changing their activation states. This spread of activation is not only between representations within the same level, e.g., between semantic representations of *girl* and *boy*, but also between representations of different levels or different types. The activation of the orthographic representation of *girl* by a visual input, for example, is assumed to spread automatically to the word's phonological and semantic representations. The modulation of the flow of activation between two types of knowledge representations by their original activation states and by other types of knowledge representation constitutes part of the interactive processes that constrain the nature and the time course of word recognition.

There is evidence to support the notion of the modulation of the spread of activation between two types of representations by a third type of representation. For instance, the spread of activation or computation from orthography to phonology has been shown to be influenced by the semantic properties of low frequency, irregular words (Strain, Patterson, & Seidenberg, 1995) and by the semantic properties of the original words on which pseudohomophones are based (see Zhou, Marslen-Wilson, Bi, Shi, & Shu, 1996 for discussion). More evidence has been collected for the automatic spread of activation between different types of knowledge representations in lexical processing. Orthographic properties have been found to influence rhyming judgment for words that are auditorily presented (e.g., Seidenberg & Tanenhaus, 1979). Words that are semantically related have been found to prime each other in a naming task, which presumably taps into phonological activation (see Neely, 1991 for a review). Orthographically similar words have been found to inhibit each other in visual-visual (e.g., Colombo, 1986) or masked (e.g., Segui & Grainger, 1990) priming lexical decision tasks, if the tasks are assumed to tap mainly into semantic activation.

These findings demonstrate that activation of one type of knowledge representation can spread automatically into other types of connected knowledge representations. These findings do not, however, allow us to track the time course of the spread of activation or the loci of priming effects. Take the widely documented semantic priming effect in naming for an example. The pronunciation of a word (e.g., *boy*) is facilitated if it is preceded by a semantically related word (e.g., *girl*). Since pronunciation is assumed to be based on the activation of *boy*'s phonological representation, a common interactive-activation account of this effect is to assume that the activation of the semantic representation of the prime *girl* spreads to the semantic representation of the target word *boy*, whose semantic activation spreads immediately and automatically to its phonological representation. When the target is actually presented, its phonological representation is activated further by the visual input, resulting in the facilitatory effect in naming. However, an alternative modular account assumes that the pre-activation of the semantic representation of *boy* is encapsulated in the semantic system and does not spread immediately to its phonological representation. Only when the target word is physically presented, does its semantic activation increase further, either through phonological mediation (Lukatela & Turvey, 1994; van Orden, Pennington, & Stone, 1990) or though direct mapping from orthography to semantics (for Chinese; Zhou, in press; Zhou & Marslen-Wilson, 1996; Zhou, Marslen-Wilson, Shu, Bi, & Tang, 1996). This semantic activation of the target word, after reaching a threshold, spreads back to its phonological representation, which may also have been activated by the direct visual mapping from orthography to phonology, jointly resulting in the facilitatory effect in naming.

These two accounts of semantic priming in naming differ in whether they allow semantic activation to spread to the corresponding phonological representations when these semantic and phonological representations have not been activated directly by their corresponding orthographic forms. Interactive-activation based theories of lexical processing allow the free flow of activation between different domains while modular theories (e.g., Forster, 1979) may not permit such spread of activation without activation from orthography. Similar contrasting accounts about the time course of spread of activation can also be constructed for other types of priming effects involving two or more types of knowledge representations.

The issues raised here are parallel to the debate between theories of language production in terms of whether access from semantics to lemma (the abstract lexical node) and to phonological representation is modular or interactive (e.g., Dell, 1986; Dell & O'Seaghdha, 1991; Levelt, Schriefers, Vorberg, Meyer, Pechmann, & Havinga, 1991). Levelt et al. (1991), for example, advocate a discrete, non-overlapping lexical access where phonological activation follows selection of a lexical item and is restricted to this item. Thus in producing *girl*, although its semantic activation spreads to its own phonological representation via the selected lexical node and may spread to the semantic representation of other related words like *boy*, the activation of *boy* is restricted to the semantic system and does not spread to its phonological representation because the lexical node of *boy* is not selected at the lemma level. Dell & O'Seaghdha (1991), on the other hand, argue for interactions between adjacent levels of representations. Because activation spreads continuously both forward and backward between all connected nodes, the activation of *girl* in both semantic and lemma levels spreads to the semantic representation of *boy*, mediating the phonological activation of *boy*.

In this paper, we examine the time course of the spread of activation from semantics to phonology and orthography and the interactivity between these different types of representations in visual word recognition. Specifically, we ask whether the spread of activation between words sharing semantic features (e.g., *girl* and *boy*) in the semantic system is encapsulated in the system or whether it has an immediate effect on the activation of phonological and orthographic representations when the semantic activation is itself *mediated* by the activation of other related words and is not supported directly by sensory input. Moreover, if semantic activation is found to spread to orthographic representations, we ask whether the phonological activation is modulated by this orthographic activation.

To address these questions, we use a semantically mediated phonological priming technique, with stimuli from two different writing systems: alphabetic English and logographic Chinese. Three experiments, one on English and two on Chinese, use essentially the same design, where a semantic prime (e.g., *girl*) is presented to pre-activate the semantic representation of a target word (e.g., *boy*). Whether semantic activation of *boy* automatically spreads to its phonological representation when *boy* is not physically presented is examined by the presence of a probe word homophonic to *boy* (i.e., *buoy*). If semantic pre-activation of *boy* spreads automatically and continuously to its phonological representation, we should obtain a facilitatory priming effect in naming *buoy* since it shares phonological properties with *boy*. On the other hand, if semantic activation is encapsulated and it facilitates phonological activation only when the word is visually presented, we should find a facilitatory effect in naming *boy*, but not *buoy*, following the prime *girl*, since only the semantic representation of *boy* is pre-activated. The issue of whether orthographic representations of semantic targets are also automatically and immediately activated is examined by comparing priming effects for homophone targets which are or are not orthographically similar to the semantic targets.

Experiment 1

The first experiment was conducted on English, where a target word (e.g., *boy*) and its homophone (*buoy*) were preceded either by a word (*girl*) semantically related to the semantic target or by an unrelated word (*view*) matched in frequency, length (both in terms of number of letters and number of syllables). The relative frequency of semantic and homophone targets was also manipulated as a between-item factor. There were 32 pairs of semantic and homophone targets which were of equal frequency, 28 pairs with low frequency semantic targets and high frequency homophone targets, and 36 pairs with high frequency semantic targets and low frequency homophone targets (Table 1).

Frequency	SemP	ConP	SemT	HomT
Equal	hero	dish	idol	idle
Low-High	hair	size	mane	main
High-Low	girl	view	boy	buoy

Table 1 Experiment 1: Design and sample stimuli
SemP=semantic prime, ConP=control prime
SemT=semantic target, HomT=homophone target

The SOA (stimulus onset asynchrony) between primes and targets was set at 100 msec. There were also 100 pairs of unrelated filler words. The mean naming latencies are reported in Table 2. Naming errors are not reported since they were too few to warrant analysis.

Frequency	Semantic		Homophone	
	Test	Control	Test	Control
Equal	527	543	529	539
Low-High	505	517	510	516
High-Low	511	516	530	542
Average	**515**	**525**	**524**	**533**

Table 2 Experiment 1: Mean naming latencies for semantic and homophone targets

Statistical analyses revealed a highly significant main effect of prime type ($F1(1, 47)=38.68$, $p<.001$; $F2(1, 93)=25.91$, $p<.001$), no interactions between prime type and target type and relative frequency of semantic and homophone targets, and no three-way interaction ($p>.1$). Thus, across the three frequency conditions, both semantic and homophone targets were facilitated by semantic primes even though there was no direct relationship between semantic primes and homophone targets. This finding is consistent with the view that the spread of semantic activation from primes to semantic targets is not encapsulated in the semantic system. The semantic activation of target words automatically spreads further to their phonological representations even when semantic and phonological activation is not supported by visual input.

The finding of equal priming effects for semantic and homophone targets suggests that orthographic as well as phonological representations of target words also received spread of activation when semantic primes were presented. According to interactive-activation based theories of lexical processing, if the orthographic representation of *boy* is activated after the presentation of its semantic prime *girl*, the spread of activation from the orthographic representation of *boy* to its phonological representation is also facilitated. However, in order to account for the equally strong priming effect for *boy* and for *buoy*, one may have to assume that the orthographic representation of *buoy* is also activated after the presentation of the prime *girl*. This is possible given that *buoy* and *boy* share many orthographic properties. If semantic and homophone targets have little orthographic overlap, we should expect to find less facilitatory effect for homophone targets. Unfortunately, this prediction cannot be tested in English since homophonic words in this language are intrinsically orthographically similar. This difficulty leads us to logographic Chinese, which is famous for its extensive homophony among words and morphemes, both orthographically similar and different.

Experiment 2

The main purpose of Experiment 2 was to investigate whether semantic activation spreads automatically to the orthographic domain when orthographic activation is not supported by visual input, and whether the orthographic similarity of homophonic targets to semantic targets influences the size of a semantically mediated phonological priming effect. To achieve this purpose, we used a similar design to Experiment 1 in Chinese, with homophonic targets orthographically different from semantic targets. The potentially different patterns of priming effects between Experiments 1 and 2 would enable us to examine more closely spread of activation and interactivity between different types of knowledge representations.

The experiment had low-high and high-low conditions in which the relative frequencies of semantic targets and homophone targets were manipulated (Table 3)[1]. There were 32 pairs of targets for each frequency condition. Another 100 pairs of unrelated characters were also used as fillers. The SOA between primes and targets was set at 57 msec. The purpose of using a slightly shorter SOA on Chinese than on English was to verify earlier evidence that semantic activation is a very early process in lexical processing of Chinese (Zhou & Marslen-Wilson, in press; Zhou et al., 1996).

Frequency	SemP	ConP	SemT	HomT
Low-High	河	跑	泉	全
	he(2)	pao(3)	quan(2)	quan(2)
	river	*run*	*spring*	*whole*
High-Low	舞	厚	歌	鸽
	wu(3)	hou(4)	ge(1)	ge(1)
	dance	*thick*	*song*	*pigeon*

Table 3 Experiment 2: Design and sample stimuli
SemP=semantic prime, ConP=control prime
SemT=semantic target, HomT=homophone target

Mean naming latencies are reported in Table 4. There was a highly significant main effect of prime type ($F1(1, 39)=34.10$, $p<.001$; $F2(1, 69)=30.17$, $p<.001$). However, unlike in Experiment 1, this priming effect interacted with the relative frequency condition ($F1(1, 39)=5.65$, $p<.05$; $F2(1, 69)=3.04$, $p<.1$), and with the target type ($F1(1, 39)=5.46$, $p<.05$; $F2(1, 59)=2.87$, $p<.1$). These interactions indicate that the priming effect in the Low-High condition is significantly larger than the effect in the High-Low condition, and more importantly, the priming effect for semantic targets is significantly larger than the effect for homophone targets. However, there was no three-way interaction between frequency, target type and priming ($F<1$), indicating that the priming effects for semantic targets, and for homophone targets, were essentially the same across frequency conditions. This was confirmed in separate analyses of priming effects for semantic targets and

[1]Throughout the paper, the pronunciations of Chinese words are given in *Hanyu Pinyin* - the Chinese alphabetic system. Numbers in brackets represent the tones of syllables.

homophone targets. Neither the priming effects for semantic targets nor the effects for homophone targets interacted significantly with the frequency condition ($p>.1$ for semantic targets, and $F1(1, 39)=4.15$, $p<.05$; $F2(1, 62)=1.50$, $p>.2$, for homophone targets).

Frequency	Semantic		Homophone	
	Test	Control	Test	Control
Low-High	589	620	549	568
High-Low	537	557	612	617
Average	**563**	**588**	**580**	**592**

Table 4 Experiment 2: Mean naming latencies for semantic and homophone targets

This confirms that the semantically mediated phonological priming effect can be found not only in English but also in Chinese, two languages that differ drastically in the way that the orthography represents sound and in terms of homophony among words and morphemes. This finding, that a semantic prime facilitates the pronunciation of a word homophonic to the word related to the prime, indicates that the spread of activation from semantic primes to semantic targets can spread further into the phonological level, even when phonological activation of targets is not supported by visual input. Because the homophone targets here had no orthographic similarity with the semantic targets, the priming effect cannot be due to the spread of semantic activation into orthographic representation.

On the other hand, the significantly smaller effect for homophone targets than for semantic targets, contrasting with the equal facilitatory effects in English, suggests that both phonological and orthographic representations of words receiving spread of semantic activation are automatically activated. In Experiment 1, the partially activated semantic representation of a semantic target (e.g., *boy*), due to the presentation of a semantic prime (e.g., *girl*), spreads not only to the phonological representation of the target, but also to its orthographic representation, which is shared to a great extent by the homophone target (i.e., *buoy*). The homophone target *buoy* probes into the pre-activation of both phonological and orthographic representations of the semantic target *boy*, leading to a facilitatory priming effect equal to the effect for the semantic target. In Experiment 2, however, a homophone target (e.g., 鸽 ge(1), *pigeon*) does not probe into the orthographic activation of the semantic target (i.e., 歌 ge(1), *song*) because there is no orthographic similarity between them, even though the homophone target does probe into the phonological representation of the semantic target, pre-activated after the presentation of a semantic prime (e.g., 舞 wu(3), *dance*). Consequently, the priming effect for the homophone target is smaller than for the semantic target when the latter is actually presented.

The above argument assumes that the orthographic overlap between target words and mediating words facilitates the phonological processing of these targets. However, this assumption may apply only when orthographically similar words map onto the same phonological representations. Our previous research found that when orthographically similar words (e.g., 田 tian(2), *field*; 申 shen(1), *apply*) map onto different phonological representations, the phonological processing of target words was delayed by the presence of orthographic primes. An inhibitory effect should also be observed for words that are orthographically similar to but phonologically different from the mediating words that are activated not by direct sensory input but by spread of semantic activation.

Experiment 3

There were two aims of Experiment 3: to ask whether equal facilitatory effects of semantically mediated phonological priming can be found in Chinese when semantic and homophone targets are orthographically similar; and to investigate whether an inhibitory effect can be found for targets that are orthographically similar to but phonologically different from semantic targets.

The design and sample stimuli are presented in Table 5. Three types of targets - semantic, homophone, and orthographic - were all complex characters and were composed of a semantic radical on the left and a component on the right (see Zhou & Marslen-Wilson, this volume). A triplet of targets (e.g., 桥 qiao(2), *bridge*; 侨 qiao(2), *live abroad*; 娇 jiao(1), *tender*) had the same right part components, which were mostly (37 out of 42 triplets) pronounceable phonetic radicals and had their own meanings, independent from the meanings of the whole complex character. The semantic and homophone targets (桥 and 侨) also had the same pronunciation (i.e., qiao(2)) while the orthographic target was pronounced in a different way. The frequencies of three sets of targets were roughly matched. The SOA between primes and targets was set, as in Experiment 2, at 57 msec. There were also 90 pairs of unrelated characters that were used as fillers.

SemP	ConP	SemT	HomT	OrtT
河	跑	桥	侨	娇
he(2)	pao(3)	qiao(2)	qiao(2)	jiao(1)
river	*run*	*bridge*	*live abroad*	*tender*

Table 5 Experiment 3: Design and sample stimuli
SemP=semantic prime, ConP=control prime
SemT=semantic target, HomT=homophone target
OrtT=orthographic target

Two triplets of targets had to be removed from the analyses because of excessive (over 50%) naming errors made for one of the targets. Mean naming latencies and error percentages based on the remaining 40 triplets of targets are reported in Table 6. In the analyses of reaction times, there was no significant main effect of prime type

($F1(1, 59)=3.10$, $.05<p<.1$; $F2(1, 117)=1.92$, $p>.1$). However, the interaction between prime type and target type was highly significant: $F1(2, 118)=9.77$, $p<.001$; $F2(2, 117)=6.45$, $p<.005$. Separate analyses of priming effects for semantic, homophonic, and orthographic targets revealed that there were significant facilitatory effects for semantic targets (19 msec; $F1(1, 59)=11.64$, $p<.005$; $F2(1, 39)=3.71$, $p=.06$) and for homophone targets (22 msec; $F1(1, 59)=9.13$, $p<.005$; $F2(1, 39)=6.11$, $p<.05$), and a significant inhibitory effect for orthographic targets (19 msec; $F1(1, 59)=5.23$, $p<.05$; $F2(1, 39)=4.94$, $p<.05$).

Semantic		**Homophone**		**Orthographic**	
Test	Control	Test	Control	Test	Control
598	617	625	647	626	607
(1.7)	(3.0)	(3.0)	(5.2)	(5.7)	(2.7)

Table 6 Experiment 3: Mean naming latencies and error percentages for the three types of targets

Clearly, the equal facilitatory priming effects for semantic and homophone targets, which were orthographically similar, replicated the finding for English in Experiment 1, but differed from the finding in Experiment 2. These effects rule out the possibility that the discrepancy between the facilitatory effects for homophone targets in Experiments 1 and 2 was due to the language of stimuli or experimental procedure. Rather, this pair of results lead us to the conclusion that orthographic representations as well as phonological representations of words which are being semantically activated are automatically and immediately activated even when these representations are not supported by sensory input. This activation of orthographic representations, which are shared partly by homophone targets in Experiment 1 and in Experiment 3 but not in Experiment 2, leads to extra facilitation in the naming of homophone targets.

The finding of an inhibitory effect for orthographic targets in the present experiment also supports the notion of automatic orthographic activation from the spread of semantic activation. The presence of a semantic prime (e.g., 河 he(2) *river*) pre-activates the orthographic and phonological representations of its semantically related words (e.g., 桥 qiao(2), *bridge*). The following presentation of an orthographic target (e.g., 娇 jiao(1), *tender*) activates its orthographic representation, which it shares in part with its orthographic neighbor 桥 (qiao(2), *bridge*). The activation of its phonological representation has to compete with the pre-activated phonological representation of 桥 (qiao(2), *bridge*), creating interference in naming.

General Discussion

The main purpose of the present research was to investigate spread of activation and interaction between different types of knowledge representations in lexical processing. Three primed naming experiments, conducted on both English and Chinese, yielded converging evidence for the automatic and immediate spread of activation from semantics to phonology and orthography. In Experiment 1, equal facilitatory effects were found for English words (e.g., *boy*) that are semantically related to their primes (e.g., *girl*) and for words that are homophonic and orthographically similar to semantic targets (e.g., *buoy*). These effects did not interact with the relative frequencies of semantic and homophone targets. Equal facilitatory priming effects were also obtained for Chinese when semantic and homophone targets were not only of the same pronunciations but also similar in orthography (Experiment 3). When homophone targets were orthographically different from semantic targets, however, a significantly smaller facilitatory effect was found in naming homophone targets (Experiment 2). When target words are orthographically similar to but phonologically different from semantic targets, a significant inhibitory effect was found for these targets (Experiment 3).

These findings indicate that in both the English and the Chinese mental lexicons, the spread of activation between words sharing semantic features (e.g., *girl* and *boy*, or 河 he(2) *river*, and 桥 qiao(2), *bridge*), activates immediately not only the phonological representations of words (e.g., *boy* or 桥 qiao(2), *bridge*) receiving the spread of semantic activation, but also their orthographic representations, even when these words are not visually presented. If homophone probe words (e.g., *buoy* or 侨 qiao(2), *live abroad*) tap into both phonological and orthographic activation, the facilitatory effect to the naming of probe words is equal to the effect of naming the semantically related words. If probe words tap only into phonological representations, as in Experiment 2, a reduced facilitatory priming effect is found in the naming of orthographically different probe words. If probe words tap only into orthographic activation and create competition with semantic targets in the computation from orthography to phonology, as in the case of 桥 (qiao(2), *bridge*) and 娇 (jiao(1), *tender*), an inhibitory effect is found in naming probe words.

An alternative explanation that does not pose problems for modular theories of lexical processing attributes the facilitatory priming effects for semantic and homophone targets to form-based associative priming (e.g., Moss, Hare, Day, & Tyler, 1994; Plaut, 1995). On this account, the co-occurrence of two phonological and/or orthographic patterns (e.g., for *girl* and *boy*) during learning forms a stable, contextual relation between the form representations and the facilitatory priming effects for homophone targets was due to the spread of activation between *form* representations of semantic primes and mediating words, rather than the spread of activation from the semantic system to phonology and orthography. However, when we re-ran Experiment 1 with semantic primes that did not have strong associative relations with target words, we found essentially the same pattern of priming effects for the semantic and homophone targets. This finding leaves the modular argument without an obvious escape route.

To summarize, using a semantically mediated phonological priming technique, the present research provides evidence, perhaps the strongest to date, from both English and Chinese that the spread of activation between words sharing semantic properties is not encapsulated in the semantic system. It spreads further into phonological and orthographic systems, activating automatically and immediately the representations corresponding to the partially activated semantic representations. Such spread of activation and interaction between different types of knowledge representations in the lexicon do not necessarily need sensory support.

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