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On Activation and Suppression in the Dual-Route Model of Reading: *Bass* the Fish or *Bass* the Guitar?*

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0. Introduction

Priming experiments focusing on homonyms have formed the basis of many previous psycholinguistic studies on reading. In the case of homophones, for example, Lukatela and Turvey (1994a,b) found that word homophones and pseudohomophones (non-words that sound like real words) both result in priming soon after their presentation, suggesting that phonology plays an important role in activating meaning and, furthermore, that the move from orthography to phonology operates quickly and automatically. But can orthography activate meaning directly? Evidence from studies of acquired dyslexia (e.g. Marshall and Newcombe 1973, 1980; Coltheart et al. 1983; Funnell 1983), in which the reading behavior of brain-damaged patients implies a dissociation between orthographic (i.e. lexical) and phonological (i.e. sublexical) methods of reading, suggests that there is a direct connection between orthography and meaning; however, evidence from normal reading (e.g. Glushko 1979, Jared et al. 1990), which shows interaction between information about regular and irregular words, indicates that both routes are at best accessed at the same time.

This paper re-examines the question of whether orthography can activate meaning independently of phonology via an experimental study of the priming behavior of non-homophonous homographs[1] (e.g. *bass* /beis/ vs. *bass* /bæs/, *tear* /tir/ vs. *tear* /teir/). In these cases are the meanings of both homographs accessed even when the sentential context is biased towards one meaning/pronunciation? In other words, can orthography activate the meaning of an inappropriate homograph before phonology can be used to prevent its access, or is this impossible because of obligatory phonological mediation?

1. Previous Research

A great deal of previous research on reading supports, on the one hand, a model in which the path from orthography to meaning is obligatorily mediated by phonology and, on the other hand, a model in which orthography may connect to meaning directly. This section will provide an overview of some of the studies on both sides of this debate (cf. Coltheart and Coltheart 1997 and Van Orden and Kloos 2005 for further reviews of this very extensive literature).

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[1] Before moving further, it would be useful to define some basic terms which are used rather differently in linguistic literature and common parlance. In this paper the terms *homophone*, *homograph*, and *homonym* (which all refer to groups of two or more words that differ in meaning) will be used as follows: *homophones* are words which coincide in phonology, but differ in orthography (e.g. *read* and *reed*); *homographs* are words which coincide in orthography, but differ in phonology (e.g. *bass* 'type of musical instrument' and *bass* 'type of fish'); and *homonyms* are words which coincide in phonology and/or orthography. In addition to this set, the term *homographone* will be used to refer to words which coincide in both phonology and orthography (e.g. *bow* 'front of a ship' and *bow* 'bend at the waist'). The terms *homophone*, *homograph*, and *homographone* are thus mutually exclusive, and *homonym* is the superordinate category including all three. Using this system of terminology, it is actually redundant then to refer to 'non-homophonous homographs', since all homographs are non-homophonous.

1.1. In Favor of Obligatory Phonological Mediation

In one influential study, Van Orden et al. (1988) found, first, that error rates in a semantic categorization task (i.e. false positive categorizations) increased for words and non-words homophonous with category members (e.g. categorizing *hare* as a body part); second, that the error rates for homophonous non-words were significantly higher than non-homophonous non-words of similar orthographic overlap (e.g. *hare* vs. *hard*); and, third, that error rates for words and non-words homophonous with the same category members were very similar to each other. These results suggest that phonology plays an important, if not inevitable, role in accessing meaning from print. Luo et al. (1998), using a semantic relatedness decision task, also found that homophones and pseudohomophones resulted in higher error rates and slower response latencies.

In the work of Lukatela and Turvey (1994a,b) cited above, word homophones and pseudohomophones displayed a priming effect. For instance, just as *toad* primed *frog*, so did the homophone *towed* and the pseudohomophone *tode*. Moreover, the priming effect of the homophones and pseudohomophones was found as early as 50 ms after the presentation of the prime, though it diminished at 250 ms. Data from orthographic controls show that orthographic similarity could not be responsible for these priming effects. These results, like those of Van Orden et al. (1988) and Luo et al. (1998), are indicative of a dominant influence of phonology in meaning activation, one that exerts itself extremely rapidly. Though Jared and Seidenberg (1991) argue, on the basis of error rate data from a categorization task with homophone stimuli, that phonological mediation exists only in the case of low-frequency words, Lukatela and Turvey did not find a significant difference between high-frequency and low-frequency words in their priming data. They conclude that phonology always mediates in the mapping of orthography to meaning, with orthography feeding forward to strengthen or inhibit the activation of the meaning pointed to by the phonology—a process that is naturally more efficient for high-frequency words. More recently, however, Becker et al. (in press) have also found word frequency effects in priming for both homophones and pseudohomophones: the more frequent the homophone or base word(s) to which a pseudohomophone is most similar, the faster and more correct the responses to the target word (cf. also Simpson and Burgess 1985, who obtained lexical decision data indicating that the more frequent meaning of an ambiguous word is accessed first). Thus, it appears that phonological mediation may only apply in the case of low-frequency words (with high-frequency words being processed via an alternate route).

In addition to these psycholinguistic studies, there is some neurophysiological evidence in support of the importance of phonology in accessing word meaning. Newman and Connolly (2004), for instance, used event-related brain potentials (ERPs) to examine the role of phonology in silent reading. They discovered that an N400 response found in the case of semantic incongruities (i.e. an incongruous word or a non-word) was not found in the case of pseudohomophones. In other words, with respect to the N400 response, non-words which sound semantically congruent elicit the same response as their semantically congruent real-word counterparts, suggesting that phonology has an influence on how the meaning of a word is integrated with its sentential context. Whereas Newman and Connolly's data consisted of ERPs, Xu et al. (2002) collected fMRI data indicating that while only phonologically oriented brain regions were activated in the execution of phonologically focused tasks, both semantically and phonologically oriented brain regions were activated in the execution of semantically focused tasks. This study strengthens the view that activation of phonology is inextricable from activation of meaning.

Phonological mediation appears, moreover, to have an effect early on in the acquisition of reading. Bosman and de Groot (1996) found that children displayed phonological interference effects in a number of different tasks: pseudohomophones were more difficult to find and/or reject than word controls in a proofreading task, a lexical decision task, and a semantic categorization task. The results of Bosman et al. (2000), in which both dyslexic and non-dyslexic children showed effects of phonological congruity in first-letter naming times, also suggest that phonology is fundamental to the process of printed word perception. Furthermore, in a four-year longitudinal study of child reading conducted by Sprenger-Charolles et al. (2003), reliance on phonological processing persisted even after the emergence of reliance on orthographic processing.

Although most of the studies cited up to this point have focused on alphabetic languages, evidence for phonological mediation comes from studies of non-alphabetic languages as well. Tan and Perfetti (1999) argue for obligatory phonological mediation in Chinese word identification on

the basis of slower response latencies to homophones and phonologically inconsistent words in a semantic judgment task and a lexical decision task. With regard to L2 acquisition of reading, Wang et al. (2003) claims that the alphabetic status of the L1 writing system affects learners' relative reliance on phonological vs. orthographic processing in reading an L2. Comparing L1 Korean (alphabetic) and L1 Chinese (non-alphabetic) learners of English, their results show that while Korean learners' error rates in a semantic categorization task were influenced by homophony, those of the Chinese learners were not, suggesting a greater reliance on phonology for the subject group with an alphabetic L1 literacy background.

Interesting results supporting the dominant role of phonology have also been obtained by Yates (2005), who found that phonological neighborhood influences the speed of visual word processing. In lexical decision, naming, and semantic categorization tasks, a large phonological neighborhood appeared to facilitate processing—not only for words, but for non-words as well. These results further suggest that phonology is fundamental to the process of reading.

1.2. Against Obligatory Phonological Mediation

Despite the preponderance of evidence that exists in favor of obligatory phonological mediation, there exists an abundance of counterevidence against this view. Much of this work has also focused on non-alphabetic languages like Chinese. For instance, Chen et al. (1995) conducted a study of the semantic processing of Chinese and found that in a semantic categorization task, false positive categorization error rates as well as response latencies were in fact the same for homophones of category members and orthographic controls; thus, phonology does not appear to have an effect here. In a later study, Zhou and Marslen-Wilson (1999) used a phonologically mediated semantic priming paradigm and found no priming in the case of homophone mediated primes that were orthographically disparate from semantic primes, again suggesting that "phonology has no inherently privileged role over orthography in constraining semantic activation" (579); instead, they argue that phonology and orthography interact in the process of semantic activation. Priming experiments with Chinese characters also figure prominently in a study by Chen and Shu (2001), whose results show negligible or relatively late priming by homophones, as well as very early orthographic inhibition. They conclude that phonological mediation in reading is not obligatory, but optional.

One might question the comparability of these studies on Chinese with studies on alphabetic languages due to the inherently different nature of the orthographic controls. However, evidence against obligatory phonological mediation comes from studies of alphabetic languages as well. Taft and van Graan (1998), for example, conducted an experiment using English stimuli and discovered that a phonological regularity effect on response latencies which was found in a naming task was absent from the results of a categorization task; in other words, there was no phonological effect in the semantic task. Damian and Martin (1998), using a picture naming paradigm with printed word distractors, found no effect of homophone distractors at an SOA of 0 or 100 ms, in contrast to what one would expect in a situation of obligatory phonological mediation. Martensen et al. (2005) used the lexical decision paradigm and found that instructing subjects to accept pseudohomophones (i.e. ignore orthographic information) led to much higher error rates and slower response times than instructing them to reject pseudohomophones (i.e. ignore phonological information), indicating that phonological information can actually be easier to ignore than orthographic information.

Just as neurophysiological data have been used to argue for obligatory phonological mediation, so too have they been used to make the opposite argument. Ziegler et al. (1999) measured event-related brain potentials in a semantic categorization task conducted in French. While phonological mediation would imply smaller N400 components associated with the processing of homophones as compared to that of orthographic controls, in fact no difference between the two was found—a result that is "incompatible with the strong phonological view according to which the only way to meaning is via a word's phonology" (775).

Further evidence against the idea of obligatory phonological mediation in reading comes from neuropsychological data. Hanley and McDonnell (1997) studied a patient, PS, who showed unimpaired access to semantics in spite of clearly impaired phonology. PS was very poor at reading non-words and unable to distinguish between pseudohomophonous and non-pseudohomophonous non-words, rhyming and non-rhyming word pairs, and homophonous and non-homophonous word pairs. In addition, when presented with one member of a homophone pair

(e.g. *air*), he was unable to access the other member (e.g. *heir*). In spite of these deficits, however, he showed good reading comprehension and spelling, indicating that connections between orthography and meaning may be preserved in spite of severe phonological impairments.

1.3. The Interaction of Activation, Suppression, and Multiple Sources of Information

The studies cited above largely focus on the process of activating meaning. However, the availability of alternate representations often entails suppressing one or more of them in order to select a unique entry. Suppression, or inhibition, has been studied in detail by Simpson and Kang (1994), who examined the priming effects found with homographones.[2] They conducted four experiments involving repeated presentations of a homographone prime (e.g. *bank* 'financial institution' vs. *bank* 'land beside a river'). In the first experiment, the primes were presented as single words before targets in five different conditions involving two presentations of the same prime word. Response times to targets on the second prime presentation show some facilitation in the first condition where the meaning of the prime accessed is the same across the two presentations, as might be expected. However, in the second condition where the meaning changes, there is marked inhibition, not simply to the level of the unrelated control, but beyond. In other words, when a target related to its prime is preceded by a prior presentation of the same prime in a totally different meaning, the target word is actually responded to more slowly than an unrelated word. Simpson and Kang take this as evidence for an inhibitory process that is "more than a straightforward withdrawal of resources" (366): an inappropriate homographone is actively suppressed. Data collected in further experiments suggest that active suppression of inappropriate meanings of a homographone results when the appropriate meaning is committed to and therefore selected; that suppression is specific to mutually exclusive, not merely irrelevant, meanings; and that the suppression effect is generalizable to sentence reading. Reading a word in context commits one to a particular meaning of a homographone in the same way that responding to a related target in the first experiment appears to commit subjects to one meaning of a homographone. Note that Reimer et al. (2001), using a mediated priming paradigm, also found evidence of inhibition—in this case, of orthographically mediated inhibition effects.

It seems clear, then, that meaning activation is more complicated than simple activation of the most appropriate meaning in context. How processes of activation and suppression interact with each other remains something of an open question, however. Perfetti et al. (2005), who investigated the priming patterns of Chinese characters, advocate a universal lexical constituency model in which words are composed of orthographic, phonological, and semantic constituents. Significantly, their model reflects a time course of these different influences in which immediate orthographic facilitation is followed by orthographic suppression and phonological facilitation. In addition, they argue that phonological activation in reading is dependent upon the structural characteristics of the particular orthography.

As for details of the time course of activation and suppression, the priming results of Ferrand and Grainger (1993) indicate that there is orthographic facilitation in the period of 17-50 ms after the presentation of a prime word and phonological facilitation after 50 ms. Lee et al. (2005) pushes the temporal threshold for phonological activation further back: they found that phonological priming by pseudohomophones did not show up in the first 60 ms, but did show up at 200 ms. These differences in the temporal development of phonological facilitation effects are accounted for by Holyk and Pexman (2004) in terms of individual differences in perceptual and phonological skill. Despite these differences, though, what seems clear is that orthographic activation occurs first and is soon followed by phonological activation (cf. Wong and Chen 1999, who argue that orthography plays the early and dominant role in reading Chinese as compared to the influence of phonology).

Remember that, as noted above, whether phonological activation necessarily occurs prior to meaning activation is not clear. The presence or absence of phonological effects in the studies that have been described may indeed result from the different task demands in these studies (cf. Van Orden and Kloos 2005). However, it may also be that this question is being framed too simplistically, especially when interactive activation models of language processing are taken into

[2] Although Simpson and Kang (1994) do not give a full list of their stimuli, all the ones they mention in the course of their paper are both homophonous and homographic (as is often the case in work on homographic words). It is assumed here that this is the case with all of their stimuli, which they refer to as homographs in deference to their orthographic identity. As summarized in fn. 1, these words are referred to in this paper as homographones.

account (e.g. Masson 1995, 1999). In a classical dual-route model (cf. Coltheart 1980), orthography feeds forward to phonology, which feeds forward to semantics, and orthography may alternatively feed forward to semantics directly. On the other hand, in interactive activation models, orthography does not just feed forward to phonology; rather, the connections between components are bidirectional, allowing for feedback between levels and complex interactions between different sources of information. The evidence in favor of such interactive models is extensive and cannot be reviewed in full here, but to give one recent example, Whatmough et al. (1999) conducted a cross-modal priming experiment and found that in addition to orthography activating phonology, phonological information appears to be able to activate orthographic representations. Thus, activation and suppression arising from 'backward' links between different levels should also be taken in consideration when analyzing psycholinguistic data.

2. The Present Study

This study builds upon previous work examining homographones and homophones by investigating the priming behavior of the third subclass of homonyms, homographs. It differs from most of the previous studies on homonyms cited above in that the homonyms are embedded in contexts to bring out one particular meaning (cf. Swinney 1979, Simpson and Kang 1994, inter alia). To reiterate, the primary objective is to explore the extent to which orthography can activate meaning independently of phonology. Secondary goals include making more explicit the time course of activation and suppression in the processing of homonymous words.

2.1. Experimental Design

The experiment conducted in this study compares the priming behavior of three kinds of homonyms—homographones, homographs, and homophones—in two experiments. There were three factors of interest in these experiments. The first factor was orthographic identity between the two members of a word pair; the second was phonological identity; and the third was identity in syntactic category.[3] These were all within-subjects factors with two levels (either identity or non-identity), resulting in eight conditions: homographones of the same category, homographones of different categories, homophones of the same category, homophones of different categories, homographs of the same category, homographs of different categories, heterographic and heterophonous words of the same category, and heterographic and heterophonous words of different categories. Of course, the last two conditions constitute control stimuli in which the prime and target are unrelated to each other, so there were effectively six experimental conditions.

An additional factor of interest was the time interval between the presentation of the prime and the presentation of the target—the stimulus onset asynchrony (SOA). This between-subjects factor had two levels (250 ms or 100 ms), thus differentiating two experiments: Experiment 1 had an SOA of 250 ms, while Experiment 2 had an SOA of 100 ms.

2.2. Stimuli

For each of the six experimental conditions, ten items were created in which the prime word occurred at the end of a sentence, which in the case of the homographone and homograph conditions was biased toward the less frequent meaning/pronunciation of the homonym (the more frequent meaning/pronunciation was not also tested in the interest of keeping the experiment a reasonable length for subjects). These items were divided into two groups of five, roughly matched for both the length and frequency of the target words. No pair of items divided across the two versions of the experiment differed from each other in length by more than one letter, or in frequency by more than a few units of the same order of magnitude (i.e. a word with frequency 100 was paired with items of frequency 200 or 300, but not with words of frequency 900 or 5000).

Although the two versions of each experiment utilized both groups of items, in one group of items the prime-containing sentences were scrambled so that prime-target pairs were unrelated. In this way, the two versions of the experiment simply differed with respect to which group of items

[3] Note that the dimension of syntactic category identity refers to the two members of the homonym pair, not the prime-target pair. An example is the pairing of *patient* (adj.) as prime and *sick* as target. The word *patient* (adj.) forms a homographone pair with *patient* (n.); *patient* (n.) should certainly prime *sick*, but *patient* (adj.) differs from *patient* (n.) in syntactic category. The reason why syntactic category is relevant here is that the structure of the sentential stimuli may lead subjects to expect words of a certain category at the end of the sentence (and perhaps to suppress words of syntactically inappropriate categories as well).

had related prime-target pairs. This division of items within a condition was necessary in order to compare response times to a target preceded by a related prime and by an unrelated prime, without exposing subjects to any target word more than once (target words could not be repeated since the initial exposure would serve as a prime itself). The division of the matched item groups across the two versions of the experiment also set up a check against the possibility that any response time patterns were item-specific.

Once the stimuli were compiled into the two versions of the experiment, they were mixed and randomized as follows. In addition to the 60 stimuli just described, another 60 stimuli were created with non-word targets. These were arranged with the 60 real-word stimuli into 20 groups of six items, which included one or two related prime-target pairs (if two, from different experimental conditions), one or two unrelated prime-target pairs, and three non-word targets. For each subject the order of the items in each block of six was randomized, and then the order of the blocks was randomized. Thus, each subject was presented with a different order of stimuli that nonetheless had stimuli from the various conditions fairly evenly distributed throughout the experiment. A complete list of the homographone, homograph, and homophone stimuli (along with the targets they were paired with in the related condition) is given in the appendix.

2.3. Methods

Subjects were told that they were participating in an experiment about attention and memory in which they would need to 'multitask' with language. They were given two tasks. The first was a lexical decision task in which they had to indicate whether or not a string of capital letters was a real word of English. The second was a comprehension/memory task in which they had to read sentences and then remember them in order to answer basic yes/no comprehension questions presented after every block of six sentences.

The comprehension questions were not relevant to the main question in this study, but they served the dual purpose of (i) preventing subjects from figuring out what the real purpose of the experiment was, and (ii) checking that subjects were actually reading the sentences and not just waiting for the last word (which was always followed by a period) to cue them for the lexical decision task. Reading the sentences was critical because they were included in the first place to provide contexts biased toward one meaning/pronunciation in the homograph conditions. Response times to the comprehension questions are not included in the results below, but the overall accuracy of the responses was checked for all subjects to make sure that they were indeed reading the sentences and not answering the questions randomly (subjects had to score at least 67% correct on the comprehension questions to be included in the final subject pool).

The experiments were run in the DmDX testing suite on a Sony Vaio PCG-TR5L laptop computer and an interrupt-driven USB digital control pad (i.e. a game controller). Subjects were presented with each sentence one word at a time, with each pre-final word staying on the screen for 500 ms. They indicated positive responses ('yes' to a comprehension question or 'yes, this is a real word of English' to a letter string) by pressing a button on the controller with their dominant hand and indicated negative responses by pressing a button on the opposite side of the controller with their non-dominant hand. The experiment was broken up into four sections with a break after each section (the length of which the subject controlled by pressing a button on the input device to continue). The entire experiment lasted approximately 20 minutes, including a warm-up session of 12 items, and subjects were compensated either USD 5 or GBP 5 for their time.

2.4. Subjects

All subjects in Experiments 1 and 2 were native speakers of American English in their 20s and 30s with at least a college education and no history of dyslexia or visual impairments. Twelve subjects participated in Experiment 1, but the data for two subjects was ultimately discarded on the basis of accuracy rates on the comprehension questions of lower than 67 percent. Thus, in the end the data for ten subjects was analyzed in Experiment 1. These ten subjects were all right-handed speakers of American English and were divided evenly between the two versions of the experiment. Experiment 2 also had a total of ten subjects. All were right-handed individuals except for one, and they were also divided evenly between the two versions of the experiment.

2.5. Results

Response time data from Experiments 1 and 2 were first cleaned of erroneous and abnormally

short/long responses and then averaged across subjects. Conditions differing only in the factor of syntactic category identity were collapsed, as this factor failed to show a main effect or interaction with other factors. Results are summarized in Tables 1 and 2 below. Note that a positive difference in response times indicates that the average response in the related condition was slower than the average response in the unrelated condition, whereas a negative difference indicates that it was faster. Data that were found to be statistically significant ($p < 0.05$) are placed in boldface.

Table 1. Average response times (ms), Experiment 1 (SOA = 250 ms)

HOMOGRAPHONES			HOMOGRAPHS			HOMOPHONES		
port/port	unrelated	diff.	*bass/bass*	unrelated	diff.	*hair/hare*	unrelated	diff.
673	669	+3	712	696	+16	666	675	-9
$p > 0.05$			$p > 0.05$			$p > 0.05$		

Table 2. Average response times (ms), Experiment 2 (SOA = 100 ms)

HOMOGRAPHONES			HOMOGRAPHS			HOMOPHONES		
port/port	unrelated	diff.	*bass/bass*	unrelated	diff.	*hair/hare*	unrelated	diff.
813	**757**	**+57**	795	790	+5	**775**	**827**	**-52**
$p < 0.001$			$p > 0.05$			**$p < 0.05$**		

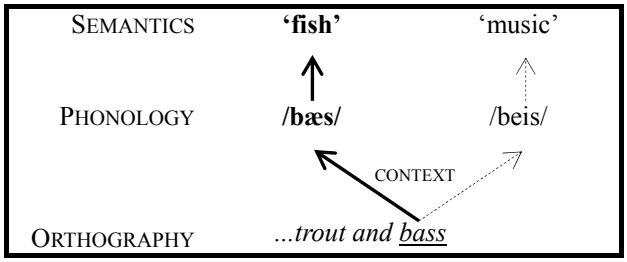
As seen in Table 2, at an SOA of 100 ms associates of homographones are processed significantly more slowly than unrelated controls, associates of homophones are processed significantly faster, and associates of homographs show no difference. 150 ms later at an SOA of 250 ms (cf. Table 1), all significant differences in response times to associates of homonyms vis-à-vis unrelated controls have disappeared.

3. Discussion

How should these results be interpreted? First, they corroborate the findings of Lukatela and Turvey (1994a,b): homophone priming is still in effect at 100 ms, but dissipates by 250 ms. Second, they contradict the findings of Simpson and Kang (1994), who looked at inhibitory processes in long-delay conditions in which one or more stimuli intervened between prime and target. Here it has been found that contextually inappropriate homographones appear to be suppressed at as little as 100 ms after visual processing and, furthermore, that this effect dissipates by 250 ms. Finally, it appears that inappropriate homographs have not been accessed in the period of 100-250 ms, as their associates show essentially the same response times as unrelated controls.

These findings have important implications for models of word reading. Most importantly, they argue in favor of phonological mediation. A significant difference in response times to associates of inappropriate homographs (i.e. facilitation or inhibition, and thereby access of the inappropriate homograph) would be required to debunk the idea of phonological mediation, but in fact no difference was found. In the case of homographs, context appears to constrain the orthography-to-phonology mapping to the appropriate phonological representation, which in turn activates the appropriate semantic representation; since the inappropriate phonological representation is never activated, or else activated significantly less than the appropriate one, spurious activation does not trickle into the semantics. This is represented in Figure 1 below, where the weight of typeface and arrow represents strength of activation.

Figure 1. Activation processes in the reading of contextualized homographs



In addition, the results suggest that inappropriate homographones are suppressed quickly and efficiently, whereas inappropriate homophones are not suppressed at all. This is a somewhat surprising finding, since there is more information available in the case of homophones (namely, disparate orthography) that could serve as input to inhibitory processes. It seems that homographones may constitute a part of the lexicon earmarked for quick inhibitory processing incorporating contextual information. In the case of homophones, on the other hand, the incidental activation of multiple semantic entries may not result in suppression of the inappropriate ones because the distinct orthographic information of the original word can feed forward to strengthen the activation of the intended entry to the point where it can be selected. In this way, it may not be necessary to suppress the activation of the inappropriate homophones.

4. Conclusion

So back to the main question: are all meanings of a homograph accessed even when only one is appropriate in context? The priming data collected in this study seem to indicate that contextually inappropriate homographs are not activated. While there may be other explanations for these data, this pattern can be accounted for by the context-incompatible phonology of inappropriate homographs, thereby supporting models of reading in which phonology mediates between orthography and semantics. These conclusions, however, are not necessarily inconsistent with a dual-route model. It may be that a phonologically mediated route from orthography to semantics constitutes a primary path, and that a secondary route connecting orthography to semantics directly is used to strengthen particular activation pathways (e.g. in the case of homophones) or to activate entries outright when the phonologically mediated route is compromised.

Although unlikely, the possibility remains that inappropriate homographs are in fact activated very early, but that the activation subsides by 100 ms (as appears to happen with inappropriate homophones somewhere in the period of 100-250 ms). Future research should thus examine the priming patterns of these different homonym categories at shorter and longer SOAs to put together a more complete picture of the time course of activation and suppression in reading.

References

Becker, D. Vaughn, Stephen Goldinger, and Gregory Stone. In press. Perception and Recognition Memory of Words and Werds: Two-Way Mirror Effects. *Memory and Cognition*.

Bosman, Anna, and Annette de Groot. 1996. Phonologic Mediation Is Fundamental to Reading: Evidence from Beginning Readers. *Quarterly Journal of Experimental Psychology A* 49(3):715-744.

Bosman, Anna, Martin van Leerdam, and Beatrice de Gelder. 2000. The /O/ in OVER Is Different from the /O/ in OTTER: Phonological Effects in Children with and without Dyslexia. *Development Psychology* 36(6):817-825.

Chen, Hsuan-Chih, Giovanni Flores d'Arcais, and Sim-Ling Cheung. 1995. Orthographic and Phonological Activation in Recognizing Chinese Characters. *Psychological Research* 58(2):144-153.

Chen, Hsuan-Chih, and Hua Shu. 2001. Lexical Activation During the Recognition of Chinese Characters: Evidence Against Early Phonological Activation. *Psychonomic Bulletin and Review* 8(3):511-518.

Coltheart, Max. 1980. Reading, Phonological Coding and Deep Dyslexia. In Max Coltheart, Karalyn Patterson, and John Marshall (eds.), *Deep Dyslexia*. London: Routledge, 197-226.

Coltheart, Max, and Veronika Coltheart. 1997. Reading Comprehension Is Not Exclusively Reliant upon Phonological Representation. *Cognitive Neuropsychology* 14(1):167-175.

Coltheart, Max, Jacqueline Masterson, Sally Byng, Margot Prior, and Jane Riddoch. 1983. Surface Dyslexia. *Quarterly Journal of Experimental Psychology A* 35(3):469-495.

Damian, Markus, and Randi Martin. 1998. Is Visual Lexical Access Based on Phonological Codes? Evidence from a Picture-Word Interference Task. *Psychonomic Bulletin and Review* 5(1):91-96.

Ferrand, Ludovic, and Jonathan Grainger. 1993. The Time Course of Orthographic and Phonological Code Activation in the Early Phases of Visual Word Recognition. *Bulletin of the Psychonomic Society* 31(2):119-122.

Funnell, Elaine. 1983. Phonological Processes in Reading: New Evidence from Acquired Dyslexia. *British Journal of Psychology* 74:159-180.

Glushko, Robert. 1979. The Organization and Activation of Orthographic Knowledge in Reading Aloud. *Journal of Experimental Psychology: Human Perception and Performance* 5(4):674-691.

Hanley, J. Richard, and Vincent McDonnell. 1997. Are Reading and Spelling Phonologically Mediated? Evidence from a Patient with a Speech Production Impairment. *Cognitive Neuropsychology* 14(1):3-33.

Holyk, Gregory, and Penny Pexman. 2004. The Elusive Nature of Early Phonological Priming Effects: Are There Individual Differences? *Brain and Language* 90:353-367.

Jared, Debra, Ken McRae, and Mark Seidenberg. 1990. The Basis of Consistency Effects in Word Naming. *Journal of Memory and Language* 29:687-715.

Jared, Debra, and Mark Seidenberg. 1991. Does Word Identification Proceed from Spelling to Sound to Meaning? *Journal of Experimental Psychology: General* 120(4):358-394.
Lee, Hye-Won, Gretchen Kambe, Alexander Pollatsek, and Keith Rayner. 2005. The Lack of Pseudohomophone Priming Effects with Short Durations in Reading and Naming. *Experimental Psychology* 52(4):281-288.
Lukatela, Georgije, and Michael Turvey. 1994a. Visual Lexical Access Is Initially Phonological: 1. Evidence from Associative Priming by Words, Homophones, and Pseudohomophones. *Journal of Experimental Psychology: General* 123(2):107-128.
Lukatela, Georgije, and Michael Turvey. 1994b. Visual Lexical Access Is Initially Phonological: 2. Evidence from Phonological Priming by Homophones and Pseudohomophones. *Journal of Experimental Psychology: General* 123(4):331-353.
Luo, Chun, Reed Johnson, and David Gallo. 1998. Automatic Activation of Phonological Information in Reading: Evidence from the Semantic Relatedness Decision Task. *Memory and Cognition* 26(4):833-843.
Marshall, John, and Freda Newcombe. 1973. Patterns of Paralexia: A Psycholinguistic Approach. *Journal of Psycholinguistic Research* 2(3):175-199.
Marshall, John, and Freda Newcombe. 1980. The Conceptual Status of Deep Dyslexia: An Historical Perspective. In Max Coltheart, Karalyn Patterson, and John Marshall (eds.), *Deep Dyslexia*. London: Routledge, 1-21.
Martensen, Heike, Ton Dijkstra, and Eric Maris. 2005. A Werd Is Not Quite a Word: On the Role of Sublexical Phonological Information in Visual Lexical Decision. *Language and Cognitive Processes* 20(4):513-552.
Masson, Michael. 1995. A Distributed Memory Model of Semantic Priming. *Journal of Experimental Psychology: Learning, Memory, and Cognition* 21(1):3-23.
Masson, Michael. 1999. Interactive Processes in Word Identification: Modeling Context Effects in a Distributed Memory System. In Raymond Klein and Patricia McMullen (eds.), *Converging Methods for Understanding Reading and Dyslexia*. Cambridge, MA: MIT Press, 373-411.
Newman, Randy Lynn, and John Connolly. 2004. Determining the Role of Phonology in Silent Reading Using Event-Related Brain Potentials. *Cognitive Brain Research* 21:94-105.
Perfetti, Charles, Ying Liu, and Li Hai Tan. 2005. The Lexical Constituency Model: Some Implications of Research on Chinese for General Theories of Reading. *Psychological Review* 112(1):43-59.
Reimer, Jason, Joseph Brown, and Thomas Lorsbach. 2001. Orthographically Mediated Inhibition Effects: Evidence of Activational Feedback during Visual Word Recognition. *Psychonomic Bulletin and Review* 8(1):102-110.
Simpson, Greg, and Curt Burgess. 1985. Activation and Selection Processes in the Recognition of Ambiguous Words. *Journal of Experimental Psychology: Human Perception and Performance* 11(1):28-39.
Simpson, Greg, and Hyewon Kang. 1994. Inhibitory Processes in the Recognition of Homograph Meanings. In Dale Dagenbach and Thomas Carr (eds.), *Inhibitory Processes in Attention, Memory, and Language*. San Diego, CA: Academic Press, 359-381.
Sprenger-Charolles, Liliane, Linda Siegel, Danielle Béchennec, and Willy Serniclaes. 2003. Development of Phonological and Orthographic Processing in Reading Aloud, in Silent Reading, and in Spelling: A Four-Year Longitudinal Study. *Journal of Experimental Child Psychology* 84:194-217.
Swinney, David. 1979. Lexical Access during Sentence Comprehension: (Re)Consideration of Context Effects. *Journal of Verbal Learning and Verbal Behavior* 18:645-659.
Taft, Marcus, and F. van Graan. 1998. Lack of Phonological Mediation in a Semantic Categorization Task. *Journal of Memory and Language* 38(2):203-224.
Tan, Li Hai, and Charles Perfetti. 1999. Phonological Activation in Visual Identification of Chinese Two-Character Words. *Journal of Experimental Psychology: Learning, Memory, and Cognition* 25(2):382-393.
Van Orden, Guy, and Heidi Kloos. 2005. The Question of Phonology and Reading. In Margaret Snowling and Charles Hulme (eds.), *The Science of Reading: A Handbook*. Malden, MA: Blackwell, 61-78.
Van Orden, Guy, James Johnston, and Benita Hale. 1988. Word Identification in Reading Proceeds from Spelling to Sound to Meaning. *Journal of Experimental Psychology: Learning, Memory and Cognition* 14(3):371-386.
Wang, Min, Keiko Koda, and Charles Perfetti. 2003. Alphabetic and Nonalphabetic L1 Effects in English Word Identification: A Comparison of Korean and Chinese English L2 Learners. *Cognition* 82:129-149.
Whatmough, Christine, Martin Arguin, and Daniel Bub. 1999. Cross-Modal Priming Evidence for Phonology-to-Orthography Activation in Visual Word Recognition. *Brain and Language* 66:275-293.
Wong, Kin Fai Ellick, and Hsuan-Chih Chen. 1999. Orthographic and Phonological Processing in Reading Chinese Text: Evidence from Eye Fixations. *Language and Cognitive Processes* 14(5/6):461-480.
Xu, Benjamin, Jordan Grafman, William Davis Gaillard, Marianna Spanaki, Kenji Ishii, Lyn Balsamo, Milan Makale, and William Theodore. 2002. *NeuroImage* 17:859-870.
Yates, Mark. 2005. Phonological Neighbors Speed Visual Word Processing: Evidence from Multiple Tasks. *Journal of Experimental Psychology: Learning, Memory, and Cognition* 31(6):1385-1397.
Zhou, Xiaolin, and William Marslen-Wilson. 1999. Phonology, Orthography, and Semantic Activation in Reading Chinese. *Journal of Memory and Language* 41:579-606.
Ziegler, Johannes, Abdelrhani Benraïss, and Mireille Besson. 1999. From Print to Meaning: An Electrophysiological Investigation of the Role of Phonology in Accessing Word Meaning. *Psychophysiology* 36:775-785.

Appendix: Experimental Stimuli

CONDITION 1A: SAME ORTHOGRAPHY, SAME PHONOLOGY, SAME SYNTACTIC CATEGORY

1. At the zoo we got to see a walrus and a *seal*. → STAMP
2. In a savings account your money will accrue more *interest*. → CONCERN
3. The baby was happily sucking on a bottle of *formula*. → EQUATION
4. For breakfast they served cereal with sweet raisins and *dates*. → TIMES
5. I don't think John is capable of doing such a dastardly *deed*. → LEASE
6. You should end that sentence with a period instead of a *colon*. → LIVER
7. After dinner we had a few glasses of *port*. → DOCK
8. No one will hire Frank because of a prior criminal *conviction*. → BELIEF
9. Katie had a cigarette but neither a lighter nor a *match*. → EQUAL
10. The game ended when an outfielder caught a fly *ball*. → PARTY

CONDITION 1B: SAME ORTHOGRAPHY, SAME PHONOLOGY, DIFFERENT SYNTACTIC CATEGORY

11. These are the new coins that the government will *mint*. → CANDY
12. The front door is so low that to enter you have to *duck*. → BILL
13. I promise you this favor won't even take a *second*. → THIRD
14. To be a teacher you have to be kind and *patient*. → SICK
15. Every year students from the local high school organize a science *fair*. → LIGHT
16. I've gotten used to the British way of driving on the *left*. → WENT
17. I love it when the leaves change color in the *fall*. → TUMBLE
18. It is illegal to discriminate on the basis of religion or *race*. → RUN
19. I joined the crew team even though I don't know how to *row*. → LINE
20. During the holy month of Ramadan Muslims pray and *fast*. → QUICK

CONDITION 2A: SAME ORTHOGRAPHY, DIFFERENT PHONOLOGY, SAME SYNTACTIC CATEGORY

21. Over the new baby's crib we hung a colorful *mobile*. → CELLULAR
22. The team won the game on the strength of their *offense*. → INSULT
23. The couple wanted to divorce but stayed together for the children's *sake*. → WINE
24. The woodcutters brought along several of their own saws and *axes*. → GRAPH
25. Where Sally's dress caught on a hook there is a small *tear*. → WEEP
26. The menu tonight is parsley potatoes and broiled sea *bass*. → TENOR
27. The child became ill after drinking water contaminated with *lead*. → AHEAD
28. For leather shoes you should use Newman's Dark Brown Shoe *Polish*. → SAUSAGE
29. Before leaving the stage, Yo-Yo Ma took a final *bow*. → RIBBON
30. Mom works for a major sewing company as the head *sewer*. → DRAIN

CONDITION 2B: SAME ORTHOGRAPHY, DIFFERENT PHONOLOGY, DIFFERENT SYNTACTIC CATEGORY

31. After breaking up with his girlfriend Jack sulked and *moped*. → BIKE
32. This alarm clock is the kind that you have to *wind*. → RAIN
33. I'm trying to lock up but the door won't *close*. → NEAR
34. With a newspaper and a coffee I am perfectly *content*. → SUBSTANCE
35. She was able to finish the task in less than a *minute*. → TINY
36. Greg swam to the side of the pool after he *dove*. → BIRD
37. The farm had a pigpen with two boars and a *sow*. → SEED
38. The soldier was kicked out of the army for trying to *desert*. → DRY
39. If you find any of this unfair please feel free to *object*. → THING
40. He's a young actor, but he already knows how to *project*. → VENTURE

CONDITION 3A: DIFFERENT ORTHOGRAPHY, SAME PHONOLOGY, SAME SYNTACTIC CATEGORY

41. Out in the fields we saw a woodchuck and a *hare*. → SCALP
42. The direction the wind is blowing is indicated by the weather *vane*. → BLOOD
43. The king re-married in the last year of his *reign*. → SNOW
44. The most difficult part of acting is crying on *cue*. → WAIT
45. When camping we gather around a fire and listen to a scary *tale*. → BACK
46. The queen bestowed a medal of honor onto the *knight*. → DAY
47. There's a draft because the window has a broken *pane*. → ACHE
48. Cyclops looks scary because he has only one *eye*. → MYSELF
49. For brunch we had bagels with cream cheese and *lox*. → KEYS
50. The boat got going once the wind caught the *sail*. → SELL

CONDITION 3B: DIFFERENT ORTHOGRAPHY, SAME PHONOLOGY, DIFFERENT SYNTACTIC CATEGORY

51. I like babies but I hate it when they *wail*. → BELUGA
52. The golf tournament was decided on the last *hole*. → ENTIRE
53. To improve your public speaking it helps to practice reading *aloud*. → PERMITTED
54. The game is over and the home team *won*. → ZERO
55. Sue returned from the post office with a bag full of *mail*. → BOY
56. The captain successfully steered the boat through the narrow *strait*. → CROOKED
57. Once the burglars were gone there were no valuables left to *steal*. → METAL
58. Jack wants to retire to a house by the *sea*. → OBSERVE
59. Johnny fetched some water from the well with a *pail*. → FAINT
60. You should be full by now considering all that you *ate*. → SEVEN