UNIVERSITY OF ALBERTA

PHONOLOGICAL EFFECTS IN CHINESE CHARACTER RECOGNITION: TASK DEPENDENT OR TASK INDEPENDENT ?

BY ©

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A thesis submitted to the Faculty of Graduate Studies and Research in partial fulfillment of the requirements for the degree of MASTER OF SCIENCE.

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Abstract

Using a position-word version of a Stroop task in four experiments, we investigated the role of phonology in Chinese character recognition and the change in the phonological effect as a function of task demands. When naming was used as the task, native Chinese speakers were significantly slower in responding to both position words and their homophonic counterparts. When the task switched to button-pressing (i.e. indicating position of word or meaning of word by pressing corresponding buttons), the homophone effect disappeared whereas the position-word Stroop effect remained. When naming and button-pressing responses were required for different trials according to the category of the stimulus on each trial, a Stroop effect was found for both position words and homophones on button-pressing trials, although in a cross-experimental comparison the homophone effect was shown not to be different from that for the pure button-pressing task. The present studies indicate that, at least to a certain extent, phonological activation in Chinese character recognition is task dependent. The results are discussed in relation to distributed models of word recognition (Seidenberg & McClelland, 1989) and the Stroop task (Cohen, Dunbar, & McClelland, 1990).

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Phonological Effects in Chinese Character Recognition

Task Dependent or Task Independent ?

Introduction

The role phonology plays in visual word recognition has long been and still is one of the central issues in reading research. Many researchers are concerned with the extent to which the phonology of words influences visual word identification. One view, usually termed phonological mediation, assumes that phonological activation occurs prior to word identification. Hence, the process of word recognition necessarily proceeds from spelling to sound then to meaning (Lesch & Pollatsek, 1993; Perfetti, Bell & Denaley, 1988; Rubenstein, Lewis and Rubenstein, 1971; Van Orden, 1987; Van Orden, Johnston,& Hale, 1988). An alternative, direct-access view, assumes that the orthographic representation of a printed word activates its meaning directly. Phonology contributes very little to the process of word recognition (Baron, 1973; Paap, Newsome, McDonald & Schvaneveldt, 1982). However, the predominant view of word recognition is the dual-route theory (Coltheart, 1978; McCusker, Hillinger, & Bias, 1981; Seidenberg, 1985) in which two independent routes, namely. a visually direct and a phonologically mediated route, are used in retrieving information about individual words from a mental lexicon. According to dual-route theories, the two independent processes are not used equally. In normal reading, visually direct access is the predominant, obligatory access route, whereas phonological mediation access is the secondary, optional route.

Although all dual-route theories assume two routes of semantic activation, they differ in the time course of the two sources. Some theories (for example, McCusker, et al., 1981; Seidenberg, 1985) assume that phonological information is activated more slowly than orthographic information and that, most of the time, it lags behind and does not have any effect on word recognition. Phonological mediation comes into play only in situations where the process of word recognition is slow, for example, in the case of low frequency word recognition (Seidenberg, 1985), word recognition with low-skilled readers (Jorm & Share, 1983) or children (Doctor & Coltheart, 1980; Rusted, 1989). Theories of this sort are sometimes termed "horse race" models (Hung, Tzeng, Salzman, & Drher, 1984). In skilled reading, most phonological activation is simply a consequence of word recognition. Phonological information is considered to be post-lexical. However, when the visual analysis is slow, and the phonological route wins the race, phonological mediation occurs and the phonological activation in this case is regarded as pre-lexical.

Evidence for the dual-route hypothesis comes from studies with a variety of experimental paradigms, including lexical decision, priming, word naming, the Stroop task, and semantic classification (or categorization). Although results of some of the studies (Rubenstein, et al., 1971; Van Orden,1987; Van Orden et al., 1988) demonstrate phonological activation in the process of accessing meaning, and strong claims of automatic phonological processes have been made, subsequent research (Brysbaert & Praet, 1992; Davelaar, Coltheart, Besner & Jonasson, 1978; Jared & Seidenberg, 1991) shows that phonological effects can be affected by the context of the stimuli. Hence, the use of phonology in visual word recognition is to some extent under strategic control.

In a lexical decision task, subjects have to decide whether a visually presented letter string is a word or a nonword. By using this paradigm, Rubenstein et al. (1971) found that lexical decisions were slower for pseudohomophones (nonwords homophonic with real words, e.g., BRANE) than for non-homophonic nonwords (e.g., BIRKT). The prelexical phonological processing of a pseudohomophone produces a phonological code that activates the corresponding real word, making the rejection of pseudohomophone difficult. Therefore, phonological activation plays an important part in word recognition. However, subsequent research has shown that the pseudohomophone effect disappears when a large proportion of pseudohomophones is included in the test list (Davelaar et al, 1978). Presumably, with a high proportion of pseudohomophones, the phonological route is abandoned because the use of phonology leads to erroneous responses. In this case, rather than being obligatory, phonological activation seems to be context-dependent. The extent to which phonological information influences lexical decision depends on the nature of the stimuli in an experiment.

Context effects have also been found in studies using priming paradigms. Perfetti et al.. (1988) reported experiments using a backward priming task. They found a reduction in the deleterious effect of a pseudoword mask following a target word when the mask shared phonemic information with the target. In the experiment, the graphemic and phonemic properties shared by a word target and a following nonword mask varied. Graphemic (e.g., RALT) and homophonic (e.g., RAIT) masks, matched for number of letters shared with a word target (e.g., rate), both showed a masking reduction effect relative to a control mask (e.g., BUSK). There was also an additional effect of the homophonic mask over the graphemic mask. In other words, the homophonic mask produced better target identification than did the graphemic mask and both produced better performance than the control mask. Because a homophonic effect occurred in the study, it was concluded that the target recognition included obligatory phonological activation and it "nonoptionally occurs during lexical access" (Perfetti, et al., 1988, p.59). This homophonic mask effect was replicated in a study with Dutch language materials by using the same paradigm (Brysbaert & Praet, 1992). However, in the same study, it was also found that the advantage of homophonic masking only arose if a considerable proportion of the masks were phonologically related to the target. More specifically, when fewer than 20% of the masks were homophonic to the target, the phonological effect disappeared. This suggests that the phonological information may not be used nonoptionally under all circumstances.

Evidence that visual and phonological routes are used differently among different individuals comes from studies with Stroop tasks (Naish,1980; Rusted, 1989). If individual differences in using visual and phonological processes can be identified, the claim that visual and phonological routes are separate processes may be supported. In a color-word Stroop task, subjects are slower in naming the color of an incongruent color word (e.g., RED printed in green ink) than naming the color of a neutral word control (e.g. FAN printed in green ink) or a color patch. The naming latency difference between color word and control is known as Stroop interference. In a card-sorting version of the Stroop task, in which subjects had to sort cards into different piles according to the ink color of words printed on each card, Naish (1980) demonstrated that color pseudohomophones or visually similar nonwords (e.g. YELLOE and YELLOT) produced longer sorting times than did nonwords that did not resemble a color word in anyway (e.g. DEVORT). But this result was true only with male subjects. For female subjects, the effect was observable only with pseudohomophones. The outcome seems to suggest that males and females tend to adopt different strategies in using phonological and orthographic information in word recognition. Another study (Rusted, 1989) done with the color-word Stroop task, showed that Stroop interference caused by pseudohomophones occurred only with low-skilled readers. Subjects with high reading skill tended to use the visual direct route more often than those with low reading skills.

Different use of phonological and orthographic information in word recognition has also been found in studies concerning the effect of word frequency. Seidenberg (1985) looked at naming latencies for Chinese and English words and concluded that most high frequency words are recognized on a visual basis without phonological mediation. Phonology only enters into the processing of low frequency words. For English, the items used were high and low frequency words that had regular or exceptional pronunciations, such as WAVE and HAVE respectively. No difference was found in naming latencies between regular and exceptional words for high frequency words. However, for low frequency words, regular words were named faster than exception words. The results were taken to mean that readers used lexical information to get the sound of familiar words but used graphemic-phoneme-correspondence rules for unfamiliar words.

Although supporting evidence for dual-route theory has been obtained with the lexical decision, word naming, priming and Stroop task, each of these tasks have problems of their own (Jared & Seidenberg, 1991). For example, most of the priming tasks and Stroop-like tasks require a vocal response to a target, but naming words aloud may not necessarily require access to the meaning of the words. Subjects may be able to name regular words solely by using grapheme-phoneme-correspondence rules. More important, even if the semantic code is accessed in a naming task, the phonological code may be activated only for the purpose of articulation. In other words, generating a phonological code may be the optimal strategy in a task involving a vocal response, but may not be so in other tasks.

A lexical decision task does not necessarily require a vocal response because responses can be made by pressing "yes" or "no" buttons. But the criterion for discriminating words from nonwords may change according to the composition of a particular set of stimuli (Davelaar, et al., 1978; Jared & Seidenberg, 1991). For instance, when most of the nonwords on the testing list are phonologically unfamiliar (i.e., nonwords do not sound like any real words), subjects may sound every letter string out and make a judgement based on the familiarity of that sound. On the other hand, responses can also be based on the orthographic familiarity of the stimuli when many pseudohomophones are included in the testing list. In both cases, responses can be made before meaning has been activated. So, results from the lexical decision task may not have any bearing on accessing meanings of words under other circumstances.

A general problem with studies using homophones or pseudohomophones is that in English when letter strings sound alike, they also look alike, because, as an alphabetic language, the English writing system represents its phonology in a relatively regular way. Although care has always been taken in matching visual similarities between pseudohomophones and non-homophonic controls, especially the number of letters shared by the two types of stimuli, one may still argue that pseudohomophones are more like words than nonword controls. Any phonological effects obtained could be attributed to orthographic factors. Martin (1982) used control nonwords that were as similar to word orthographically as were pseudohomophones. For instance, the pseudohomophone WHALL was constructed from word WALL in the same way used to construct the control nonword THALK from word TALK. When this kind of orthographic matching was employed, the pseudohomophone effect disappeared in a lexical decision task. Because visual control stimuli used in studies concerning phonological influence in word recognition usually are not constructed as they were in Martin's (1982) study, it is hard to determine how much of the phonological effect is actually attributable to orthographic similarities.

The extent to which writing systems encode phonology is different across orthographies (Hung & Tzeng, 1981). It is possible that the importance of phonology in the process of getting meaning from print varies across different writing systems. In an alphabetic writing system such as English, letters or letter clusters generally correspond to phonemes, but there are exceptional words that do not follow grapheme-phoneme-correspondence rules. In Serbo-Croatian, a typical syllabic writing system, grapheme and phoneme have a strict and direct correspondence. In contrast, written forms in Chinese represent morphemes rather than phonemes. Thus, it is reasonable to assume that in identifying Serbo-Croatian words, readers may make more use of phonology. On the other hand, reading Chinese characters may involve more direct mapping between visual representation and meaning, because there is no obvious grapheme-phoneme-correspondence rules to apply (but see, Seidenberg, 1985). Assembled phonology obtained via grapheme-phoneme-correspondence rules used to be considered as the only form of prelexical phonology (Coltheart, 1978) and the phonological activation in Chinese character recognition was regarded as postlexical, although recently other forms of computational prelexical phonology have been proposed (Seidenberg and McClelland, 1989; Van Orden, Pennington & Stone, 1990). Nevertheless, it is conceivable that if direct evidence for independent visual access can be obtained with Serbo-Croatian materials, or direct evidence for obligatory prelexical phonological activation can be obtained with Chinese materials, then a strong case of supporting either the dual-route hypothesis or the phonological mediation hypothesis may be provided. A number of studies done with Serbo-Croatian materials consistently support the claim that phonological activation occurs nonoptionally (for review, see, Lukatela & Turvey, 1991).

Results of studies done with Chinese materials are less consistent. Some early studies (Tzeng, Hung & Wang, 1977; Hung &Tzeng, 1981) show that phonology is used when memory and comprehension are required. Tzeng et al. (1977) carried out two experiments, in which Chinese subjects were asked to memorize a list of unrelated target characters presented visually. Before recalling the target characters, the subjects were asked to shadow a series of syllables that were phonologically similar or dissimilar to the target characters. The results showed a huge interference effect due to phonological similarity. Other studies (e.g., Seidenberg, 1985) on single word reading show that phonology comes into play only when characters are low frequency. A Chinese compound character always comprises more than one radical. In a phonetic compound, one of the radicals is a simple character by itself and has a similar or identical pronunciation to that of the compound character. Seidenberg (1985) compared the naming times for Chinese phonetic compounds and that for nonphonetic compounds. Both types of characters could be high or low frequency. It was found that naming latencies were faster for phonetic compounds than for nonphonetic compounds, but only for low frequency characters and not for high frequency characters.

A recent study (Perfetti & Zhang, 1991) which examined the phonological process in Chinese characters recognition provided evidence that in Chinese word recognition, activation of phonology occurs nonoptionally as a consequence of word identification. A backward priming paradigm similar to the one used in Perfetti et al. (1988) study was employed in a Chinese context. Native Chinese speakers were required to identify visually presented Chinese character targets that were followed shortly by Chinese character masks. According to features shared by the target (e.g., /hong/, red) and mask, character masks were defined as homophonic mask (e.g., /hong/, great), graphemic mask (e.g., /jiang/, river), semantic mask (e.g., /zhu/, red) and control mask (e.g., /ru/, milk), which shared sound, visual properties, meaning and nothing with the target, respectively. The subjects' task was to identify each target character that was followed first by a word mask and then by a pattern mask. With a short interstimulus interval (35 ms) between target and mask during which, the authors believed, only a prelexical processing could occur, the targets followed by graphic masks were recognized better than the targets that were followed by control masks. Perfetti and Zhang (1991) argue that in Chinese word recognition there is no prelexical phonological activation; that is, word recognition is not mediated by phonology because homophonic masks did not show any facilitative effect on the recognition of the target characters. In the same study, a forward priming task was also used, in that character masks served as primes preceding the target. Under a long interstimulus interval (180 ms) condition, significant homophonic effects and semantic effects were evident; that is, naming latencies were shorter for targets that were preceded by homophonic primes or semantic primes than by controls. These results led the authors to conclude that although phonology is not necessary for accessing the Chinese lexicon, it is activated postlexically on a routine basis.

However, there is at least one problem with Perfetti and Zhang's (1991) study: In the experiment where a phonological effect was found, a naming task was used. As discussed earlier in this section, naming words aloud may induce specific strategies that may or may not be used in normal silent reading. The purpose of present study was to investigate whether vocal and manual response requirements affect the phonological processing of Chinese characters. To accomplish this purpose, we adopted a position-word version of the Stroop task in which both vocal and manual responses could be used. In this task, subjects see a position word in the center of the screen and an asterisk above, below, to the left or to the right of that word. Subjects could be asked to: respond to the meaning of the word vocally; respond to the meaning of the word by pressing a corresponding button on a button pad; respond to the position of the word relative to the asterisk vocally; or respond to the position of the word by pressing a button. If naming does induce the use of a phonological strategy, then Stroop interference with homophones of position words is expected in a naming task but not in a button-pressing task. On the other hand, if task demands do not affect the Chinese character recognition and phonological activation is obligatory, then Stroop interference with homophones should been seen in both naming and button-pressing tasks.

Experiment 1

The goal of Experiment 1 was to examine the role of phonology and orthography in reading Chinese characters using a Stroop task with a manual response. Generally, the Stroop effect is smaller when a manual response is required than when a vocal response is required (Macleod, 1990). Presumably, naming is a compatible response mode for word reading and button-pressing is a suitable response mode for responding to positions. Because of the stimulus and response compatibility, in a position word Stroop task, Stroop effects are virtually absent with a button-pressing response (Walley, unpublished). By using manual response, Palef and Olson (1975) found that Stroop interference occurred only when the relative positions of the words were to be indicated while the absolute position of the words was always in the center of the screen. In the present studies, a relative position task similar to Palef and Olson's (1975) was used. Position words as well as their homophones, orthographically similar words, semantically similar words and unrelated control words were tested in the experiment. If strokes of Chinese characters are the perceptual units in word recognition, orthographically similar words that shared a number of strokes with position words would cause longer response times than unrelated controls. Thus, an orthographic effect was expected. Because of the semantic spreading activation from the semantically similar words to position words, a Stroop interference effect was also expected for the semantically similar words. For homophones, the results could turn out in two ways. First, if the activation of phonology in reading Chinese is obligatory, then homophones would produce a longer response time than unrelated controls. Second, if the use of phonology in Chinese character recognition is task dependent and phonological activation occurs only when vocal response is required, then a homophonic effect may not occur in this experiment.

Method

Subjects. Eighteen undergraduates who were native Chinese speakers participated in a half hour session for course credit. All were originally from Hong Kong and spoke Cantonese dialect. All subjects had normal vision or corrected-to-normal vision.

Stimuli and design. The stimuli consisted of six sets of four Chinese characters. So, the total of 24 stimulus characters were formed. The words in position set were " " (above, /shang/), " " (below, /xia/), " " (left, /zuo/) and " " (right, /you/). The graphemic set, homophonic set and semantic set were selected based on features they shared with corresponding position words (see Figure 1). Graphemically similar words shared some strokes with position words, and semantically similar words had meanings similar to position words. All homophones had the same pronunciations as corresponding position words in both Cantonese and Mandarin except word " " (hinder, /zu/) which was homophonic with word " " (left, /zuo/) only in Cantonese. Visual complexity of Chinese characters was measured by number of strokes of each character. The visual complexities of position words and graphically similar words were comparable, with mean number of strokes of 4.0 and 4.2 respectively.

	stimulus type					
	position word	homophone	graphic similar	semantic similar	control I	control II
Character	下	夏	不	低	白	原
Phonetics in Mandarin	xia	xia	bu	di	bai	yuan
Phonetics in Cantonese	hah	hah	ba'	da'i	baahk	yuhn
Number of Strokes	3	9	3	7	5	9

Figure 1. Examples of Stimuli in Experiment 1.

The mean numbers of strokes for homophones (7.2) and semantically similar (7.2) word were also comparable. However the homophones and semantically similar words were noticeably more complex than the position words and the graphically similar words. To eliminate visual complexity as a potential confounding variable, we selected two sets of control words:

One with complexity to match the position words and graphically similar words, and the other to match the semantically similar words and homophones. All characters used in the experiments to be reported were high frequency words ranging from 6320 per million to 32 per million (Beijing Language Research Institute, 1986).

Each character occurred three times in each of the four blocks of trials with an asterisk appearing once in each of the three possible conflicting positions. For instance, asterisks could appear to the left, to the right and above the word "   " (above) on different trials, making three correct responses as pressing right, left and below buttons on the button pad. Congruent conditions in which correct responses were consistent with the meaning of the stimuli were not included in the experiment. The total number of trials was 288 with 72 trials in each block. All subjects were assigned to all conditions, producing an entirely within-subjects design. The order of stimulus presentations in each block was individually randomized for each subject.

Apparatus and procedure. Subjects were tested individually in a dimly lit room. The stimuli were displayed on a nine inch video monitor (Electrohome model ESM-914, equipped with a P4 phosphor) controlled by an Apple II+ microcomputer. At a viewing distance of approximately 80 cm, the characters subtended a visual angle of about 1.2 degrees horizontally and 1.2 degrees vertically. A button pad was prepared in that a set of five buttons mounted in a shallow box that was ten cm square and about two cm high. One button was mounted in the center of the box with the other buttons to the left, right, above and below the center button. Each button was separated from the center button by 25 mm.

Subjects initiated each trial by pressing a button held in the non-dominant hand when the word READY appeared on the monitor. Each trial began with the 500 ms presentation of a plus sign which served as a fixation point in the center of the screen. The plus sign was replaced by one of the stimulus characters for a duration of 100 ms, and at the same time an asterisk appeared at one of the three possible locations. The trial terminated 2000 ms after the onset of the stimulus, and the READY signal for the next trial came on 100 ms later.

Subjects were instructed to orient their eyes towards the fixation point and respond to the positions of presented characters relative to asterisks by pressing corresponding buttons on the button pad. Speed and accuracy were emphasized equally. All subjects had 24 practice trials which consisted of all 24 characters each with an asterisk appearing in a conflicting position. Subjects took a two minute break after the completion of the second block of trials.

Results and Discussion.

For each trial, a response time of more than 2 sec was considered as error (This procedure was followed for all of the reported experiments). Stroop interference was calculated as the differences in response times and error rates between experimental trials and control trials. Response times, error rates and Stroop interference for position words, graphically similar words, homophones, semantically similar words and unrelated controls are shown in Table 1.

An overall analysis of variance was conducted on the mean response times with stimulus type (position words, graphically similar words, homophones, semantically similar words and control words) and character type (above, below left and right) as within-subject factors. Main effects of stimulus type, $F(5, 85) = 2.23$, $MSe = 2393$, $p > .05$, was not significant. Planned comparisons with Dunnett's tests (Kirk, 1982) among stimulus types were carried out and none of the comparisons reached significance. Considering that the phonological effect was of the greatest interest in carrying out present study, we conducted a 2 X 2 analysis of variance with variables of stimulus type (position words vs. homophones) and experimental conditions (experimental vs. control).

The main effect of experimental vs. control conditions was obtained, $F(1, 17) = 6.77$, $MSe = 2389$, $p < .05$. The main effect of stimulus type, $F(1, 17) = 3.96$, $MSe = 1592$, $p > .05$, and the interaction between stimulus type and experimental condition, $F(1, 17) = .06$, $MSe = 3411$, $p > 1$, did not reach significant level. Further t tests showed that the Stroop interference effect (difference in response times between experimental and control conditions) with position words, $t(17) = 2.33$, $SE = 7.29$, $p < .05$, was significant, whereas the interference with homophones, $t(17) = 1.78$, $SE = 7.29$, $p > .10$, was not significant. A t test for the difference between the semantically similar and control words indicated a nonsignificant semantic effect, $t(17) = 2.02$, $SE = 8.46$. Because the mean error rate was low (2.2%), the error data were not analyzed statistically.

Table 1

Mean Response Times (in Milliseconds), Error Rates (in %) and Stroop Interference For Position words, Homophones, Graphically similar Words, Semantically similar words and Unrelated Controls.

	Stimulus Type					
	Position	Graphic	Homophone	Semantic	Control 1	Control 2
Response time	666	649	655	659	649	641
Error rate	3.8	2.9	1.5	2.5	1.7	1.0
Stroop interference	17 (2.1)	0 (1.2)	14 (.5)	18 (1.5)	--	--

Note: "Control 1 " are control stimuli for position words and graphic similar words; "Control 2" are control stimuli for homophones and semantic similar words.

Basically, the overall analysis of variance with all six levels of stimulus type entered did not show any reliable interference effects. The 2 X 2 analysis of variance with position words and homophones indicated that Stroop interference occurred with position words, but not with homophonic words. However, the size of the effects with the two types of stimulus were similar (17 ms for position words, 12 ms for homophones) and the difference between the position word effect and homophone effect was not reliable (indicated by nonsignificant interaction between the two effects). Nevertheless, the homophonic effect was not statistically significant. The pattern of the results suggests that at least on some of the experimental trials subjects recognized the position words, and, as a consequence, the meanings of the position words slowed the response times on those trials. If phonology is activated in the process of word recognition, the activated phonology of homophones may in turn activate the meanings of corresponding position words and if the activation of meaning is strong enough then Stroop interference with homophone should occur. The present experiment does not provide such evidence. However, the conclusion that phonology is not activated in a button-pressing task cannot be drawn for a couple of reasons. First, the task used in the experiment did not require any operations based on semantic information in the stimuli. It is possible that for some subjects or for all subjects on some trials, semantic processing of the words was not carried out, especially if subjects realized that identifying stimulus words disrupted their performance. After the experiment, some of the participants reported that they could avoid identifying stimulus words by defocusing their eyes or by looking at the asterisks. Therefore, meaning may not have been accessed on every trial for every subject. Second, on trials where the stimulus words were identified, phonological information might be activated. The null result of homophone effect could be due to the low sensitivity of the task. Therefore, more direct evidence for strategic phonological activation is needed.

Although the size of the effects for position words and semantically similar words were identical (17 ms for both), the semantic effect did not reach significant level. One of the reasons for the absence of semantic effect is in line with the view that under the experimental conditions of the present study, semantic processing of the stimulus words was minimized.

Given the fact that target character identification was improved by a following graphemic mask in Perfetti and Zhang (1991) study, the absence of graphic effect in the present experiment seems surprising. However, a close examination of the stimulus characters used in the two studies showed that most of the characters (32 out of 34) used in Perfetti and Zhang (1991) study were compound characters and the graphemic masks shared radicals with corresponding target characters, whereas position words used in the present experiment were simple characters and the graphically similar words shared strokes rather than radicals with the corresponding position words. The results obtained from these studies are consistent with the notion that the salient units of language perception in Chinese are radicals and simple characters rather than strokes (Hoosain, 1991). Radicals or simple characters can be perceived in a wholistic way. Therefore, the graphically similar words and position words used in the present experiment were actually perceptually dissimilar, although they shared some visual features with each other.

Experiment 2

Because the major reason for doing this study was to investigate the role of phonology in reading Chinese, the graphically similar words and semantically similar words were dropped from Experiment 2. In addition to position words, homophones and their corresponding controls, a new set of stimuli, orientation words, were added. These consisted of " " (/dong/, east), " " (/nan/, south), " " (/xi/, west) and " " (/bei/, north). In order to ensure the semantic processing of stimulus words, subjects were instructed to respond differently according to the category of the stimulus. When the words were orientation words, subjects were asked to respond to the meaning. When the stimuli were position words, homophones and control words, subjects were asked to respond to the relative positions of the words. The logic here is that when subjects are required to make different responses based on semantic category, each stimulus must be identified prior to selecting a response. Because Stroop interference comes from a conflict between the meaning of stimulus words and their position, a strong Stroop interference with position words was expected. If activation of phonology is obligatory, then homophones would cause more interference than unrelated controls. If the use of phonology in Chinese character recognition occurs only when vocal response is required, then a homophonic effect would not occur and the view that the use of phonology in reading Chines is task-dependent may be supported.

Method

Subjects. Twenty native Chinese speakers participated in this experiment on a volunteer basis. Among these subjects, nine spoke Mandarin dialect and eleven spoke Cantonese dialect. All subjects had university or above level of education and their age ranged from 20 to 36. All of them had normal vision or correct-to-normal vision.

Stimuli. The materials included position words, homophones and corresponding controls used in Experiment 1. A set of orientation words consisting of " " (/dong/, east), " " (/nan/, south), " " (/xi/, west) and " " (/bei/, north) were also included in the materials. Orientation words were repeated twice, making total of six sets of stimuli of which one third were orientation words. The experimental design was the same as that in Experiment 1.

Procedure. Subjects were asked to make different responses according to the semantic category of the stimuli. When the stimulus was an orientation word, subjects responded to the meaning of the word by pressing the corresponding button on the button pad. For instance, the correct response to word " " (south) was to press the below button. Likewise, correct responses for word " " (east), " " (west), and " " (north) were right, left and above button-pressings respectively. When the stimulus was any word but orientation words, subjects responded to the position of that word relative to the asterisk as in Experiment 1. Otherwise the procedures and apparatus were identical to those of Experiment 1.

Results and Discussion

Due to the difficulty of recruiting Cantonese speakers, Chinese Mandarin speakers also participated in this and subsequent experiments.

Because word " " (hinder) was homophonic with word " " (left) only in Cantonese, data from word " " (left) and its counterpart in each stimulus set were excluded in data analyses. The purpose of introducing orientation words was to ensure that the word was identified on each trial. There was no particular theoretical interest in the data of orientation words and they were left out of the data analyses. The mean response times, error rates and Stroop interference for position words, homophones, and corresponding controls are shown in Table 2. It may be seen that relatively large interference was obtained for position words, whereas the interference was relatively small for homophones. The error data were consistent with response time data and there was no speed-accuracy trade off.

A 2 X 2 analysis of variance was conducted on the response time data with variables of experimental condition (experimental vs. control) and stimulus type (position words vs. homophones). Response times were significantly slower in experimental conditions than in control conditions, $F(1, 19) = 53.75$, $MSe = 15722$, $p < .001$. The interaction between experimental condition and stimulus type was also significant, $F(1, 19) = 49.37$, $MSe = 8998$, $p < .001$.

Table 2

Mean Response Times (in Milliseconds), Error Rates (in %) and Stroop Interference For Position words, Homophones and Control Words.

	Type of Stimulus			
	Position word		Homophone	
Conditions	Response time	Error rate	Response time	Error rate
Experimental	955	6.8	765	0.8
Control	774	1.8	753	1.1
Interference	181*	5.0	12	-0.3

* $p < .05$

Planned comparisons between position words and controls, homophones and controls were carried out. The analyses showed that Stroop interference for position words, t (19) = 10.64, SE = 17.03, p <

.001, was significant, but the interference for homophones, $t(19) = .86$, $SE = 13.99$, $p > .05$, was not significant. Because the mean error rate was low (2.6%), error data were not analyzed statistically.

The evidence that meaning was accessed in performing the task comes from the fact that it is the incongruent meaning of words that causes the delay in response times. If the semantic information were not activated, then position words would have caused the same amount of interference effect on performance as the unrelated control words would. Consequently, the Stroop interference would not have occurred for position words. In fact, in performing the Stroop task, subjects cannot avoid processing the presented word stimuli. Thus, the activated meanings form the competing response candidates that must be suppressed, making the decisions more difficult. In previous studies with color-word Stroop task (e.g., Dennis & Newstead, 1981; Rusted, 1989), when color naming was required, pseudohomophones of color words (e.g., PINC for PINK) produced slower responses than control letter strings (e.g., PINN) indicating that phonology is activated in the process of color naming. Presumably, pseudohomophones activate phonological codes which in turn activate meanings of the color word counterparts. As a result, the latencies for color naming are slowed. The lack of a strong homophonic effect in the present experiment suggests that with manual responses, the access of meaning is accomplished directly from visual representation; phonological information is not used in the process. If phonology were activated, a homophone would have activated meanings of both the homophone and its corresponding position word, and the meaning of the position word in turn would have caused Stroop interference.

Experiment 3

The failure to find Stroop interference with homophones in Experiment 2 suggests that the phonology of a word is not activated when phonological information is irrelevant. If a vocal response induces the use of phonology in word recognition, then in a naming task phonology should be activated. Consequently, Stroop interference should be observed with position words as well as with homophones. This prediction is tested in the present experiment by requiring subjects to name the positions of the position words and homophones.

Method

Subject. Twenty subjects from the same population as in Experiment 2 participated. Seven of them spoke Cantonese and rest of them spoke Mandarin. All subjects had normal or corrected-to-normal vision. The age range was from 22 to 34.

Materials and design. The experimental materials and design were identical to that of Experiment 2.

Procedure. The procedure was the same as in Experiment 2 except that instead of button-pressing, subjects were asked to name the position of the words or the meaning of the words aloud. More specifically, subjects were instructed to name the positions of the words relative to the asterisks for all stimuli except orientation words. When the stimuli were orientation words, subjects were asked to say above, below, left and right in Chinese (either Mandarin or Cantonese) according to the correspondence between direction and orientation in a geographic map. For example, the correct response to word " " (south) was to say " " (below) aloud. Likewise, the correct responses for words " " (east), " " (west), and " " (north)) were to say right, left and above in Chinese respectively.

Vocal responses were detected by means of a BRS-Foringer model VOR-001 voice operated relay. Response times were measured for the first vocal response after the onset of the stimulus. Errors or extraneous sounds prior to the response were recorded by the experimenter.

Results and Discussion

The mean response times and error rates are shown in Table 3. Generally, position naming was slower than button pressing (Experiment 2) with the mean response times of 918 ms and 812 ms respectively. The Stroop interference with position words was relatively large, whereas the interference effect with homophones was small. Error data were consistent with response time data: High error rates were associated with long response times.

A 2 X 2 analysis of variance was conducted with variables of stimulus type (position word vs. homophone) and experimental condition (experimental vs. control). The main effect of stimulus type and experimental condition were both significant with F (1, 19) = 111.72, MSe = 10692.5, $p < .001$, and F (1,19) = 38.07, MSe = 11759.7, $p < .001$, respectively. The interaction between stimulus type and experimental condition was also significant, F (1,19) = 48.01, MSe = 7448.8, $p < .001$. Planned comparisons between position word and control, homophone and control were carried out. The naming latencies for position words were significantly slower than that for their controls, t (19) = 13.85, SE = 15.76, $p < .001$, and as were that for the homophones, t (19) = 3.93, SE = 16.3, $p < .01$. Error rates were small (2.3%), so error data were not statistically analyzed.

Table 3

Mean Response Times (in Milliseconds), Error Rates (in %) and Stroop Interference For Position words, Homophones and Control Words.

	Type of Stimulus			
	Position word		Homophone	
Conditions	Response time	Error rate	Response time	Error rate
Experimental	1,071	4.0	907	2.2
Control	853	1.1	843	1.8
Interference	218*	3.9	64*	0.4

* $p < .01$

When position naming was used, reliable Stroop interference with both position words and homophones was obtained, and the effect was larger for position words than for homophones. For the observed homophone effect to have occurred there must have been phonological activation in the process of character identification. The phonological representations derived from homophones activated meanings of both homophones and their corresponding position words. If, presumably, orthography represents a strong constraint on semantic activation, then the activation of position meaning from homophones should be weaker than that from position words themselves. This can account for the smaller homophone effect. The fact that the activation of phonology was disruptive to the performance suggests that in this particular task the subjects' control over phonological activation may be limited.

The results from Experiment 2 and 3 suggest that task demands may have an effect on the use of phonology in visual word recognition. When a vocal response was required, phonology was inevitably activated, whereas when a manual response was required, evidence for the activation of phonology was weak.

One possible reason for the absence of homophonic effect in Experiment 2 is that in a task where only manual responses are involved, phonologically related information processing may not be necessary. Presumably, the meaning of a word can be activated directly via its visual representation, bypassing the phonological mediation route and the associated interference. But when position naming task was used in Experiment 3, the articulation of vocal responses may facilitate the processing of phonologically relevant information. In other words, phonological activation is induced by the vocal response requirement. The use of phonology can be voided when only a non-vocal response is needed.

However, the results can also be explained in terms of response sensitivity. It is reasonable to assume that vocal responses are more susceptible to the influences of phonological codes than manual responses. Therefore, it is possible that in both the manual and vocal tasks, the phonology of a word was activated. However, the phonological activation was capable of interrupting position naming but not button-pressing. To rule out this response-sensitivity interpretation, we compared the response times of manual responses to homophones in a task in which vocal responses were also involved.

Experiment 4

Although results of Experiment 2 and 3 can be discussed in terms of task specific effects, an alternative interpretation in terms of response sensitivity is also reasonable. These two possibilities are tested in the present experiment by asking the subjects to read the orientation words aloud but press buttons for the relative positions of other stimuli. If the homophone effect in Experiment 3 is due solely to the sensitivity of the vocal response to interference from phonology, then Stroop interference with homophones should not be found in this experiment. If, on the other hand, phonological activation is enhanced generally whenever vocal response are used, then a homophone interference effect would be expected. Moreover, if both mechanisms contribute to the phonological effects found in the previous experiment, then the interference effect with homophones would be smaller than that in Experiment 3.

Method

Subjects. A new group of 20 subjects from the same population as in Experiment 2 and 3 participated. All were native Chinese speakers with 6 speaking Cantonese and 14 speaking Mandarin. The age range was 24 to 33. All participants had normal vision or corrected-to-normal vision.

Materials and design. Experimental materials and design were identical to that of Experiment 2 and 3.

Procedure.The subjects were required to read the word aloud when the presented stimulus was an orientation word. When the stimulus was a position word, a homophone, or a control word, subjects were asked to indicate the position of that word relative to the asterisk by pressing the corresponding button on the button pad. Otherwise, the procedure and apparatus were identical to those used in Experiment 3.

Results and Discussion

Within experiment analysis. The mean response times and error rates for position words, homophones, and controls are shown in Table 4. Again a large Stroop interference effect was evident with position words, whereas a relatively small effect with homophones was found. There was no speed and accuracy trade-off. A 2 X 2 analysis of variance was performed on the response times with factors of experimental condition (experimental vs. control) and stimulus type (position words vs. homophones). The main effects of stimulus type and experimental condition were both significant, F (1, 19) = 78.35, MSe = 7987.8, $p < .001$, and F (1,19) = 27.46, MSe = 5532.1, $p < .001$. The interaction between stimulus type and experimental condition was also significant, F (1,19) = 28.24, MSe = 6893.0, $p < .001$. Planned comparisons between position word and control, homophone and control were conducted. The naming latencies for position words were significantly slower than their controls, t (19) = 8.11, SE = 15.16, $p < .001$. The interference with homophones was also significant, t (19) = 4.80, SE = 6.44, $p < .01$. Error rates were small (1.4%), so, error data were not statistically analyzed.

Table 4

Mean Response Times (in Milliseconds), Error Rates (in %) and Stroop Interference For Position words, Homophones and Controls.

	Type of Stimulus			
	Position word		Homophone	
Conditions	response time	error rate	response time	error rate
Experimental	811	3.2	705	.8
Control	688	.7	674	.9
Interference	122 *	2.5	31*	-.1

* $p < .05$

Cross-experiment analysis. Stroop interference effects with position words and homophones in Experiment 2, 3, and 4 are shown in Table 5. A 3 X 2 analysis of variance was carried out on response times with the three experiments (Experiment 2, 3, & 4) and stimulus type (homophone vs. control) as factors. The main effect for experiment was significant, $F(2, 57) = 16.75$, $MSe = 69999.1$, $p < .001$, as was the homophone effect, $F(1, 57) = 20.86$, $MSe = 5317.4$, $p < .001$. The interaction between experiment and homophone also reached the significant level, $F(2, 57) = 3.67$, $MSe = 5317.4$, $p < .05$. Because of the significant experiment X homophone interaction, pairwise comparisons among interference effects in the three experiments were conducted. The effect for the naming task (Experiment 3) was reliably larger than that for the button-pressing task (Experiment 2), $t(19) = 2.38$, $SE = 21.8$, $p < .05$. However, the difference between naming task (Experiment 3) and mixed task (Experiment 4) did not reach significant level, $t(19) = 1.81$, $SE = 17.6$, $p > .10$, neither did the difference between button-pressing task (Experiment 2) and mixed task (Experiment 4), $t(19) = 1.27$, $SE = 14.9$, $p > .10$.

Table 5

Stroop Interference Effects on Response Times (in Milliseconds) For Position words, Homophones in Experiment 2, 3 and 4.

	Experiment 2	Experiment 3	Experiment 4
position word effect	181	218	122
homophone effect	12	64	31

In summary, an interference effect for homophones was found whenever a vocal response was involved in the task, even when the vocal response was not required on homophone trials. When the task required purely manual responses, the homophone effect disappeared. However, the cross-experiment analyses showed that the homophone effect for mixed task (Experiment 4) was not statistically different from that for either the naming (Experiment 3) or the button-pressing task (Experiment 2).This pattern of results indicates that although response sensitivity alone cannot account for all the effects observed, it may contribute to part of the phonological effect found in naming task. More importantly, task demands may also affect the relative use of phonology in these tasks. If the vulnerability of vocal response to phonological interference were the only reason for homophone effects, then there would have been no homophone effect in the present experiment, because the homophone effect obtained was on manual response trials only. Therefore, it is possible that vocal responses enhance the activation of phonology. The enhanced phonological activation in turn causes an observable interference effect in the mixed task. However, the nonsignificant results from the cross-experiment comparisons make the argument weak.

General Discussion

The present studies showed that in Chinese character recognition the activation of phonology occurred inevitably when position naming was required in a Stroop task, despite the fact that phonological activation had a negative effect on performance. Subjects spent more time on naming the position of a conflicting position word homophone than that of a control word which did not resemble position words in any respect (Experiment 3, naming task). Furthermore, response time was longer for indicating the position of a homophone by pressing a button if the words had to be read aloud on some other trials (Experiment 4, mixed task). In contrast, there was no strong evidence for phonological activation when the task involved only manual responses (Experiment 1 & 2, button-pressing task). The comparisons of homophone effects among different tasks showed that the homophone effect for mixed task was not reliably different from that for either the naming task or button-pressing task, whereas the effects for the latter two tasks differed from each other.

These results could be taken to mean that to a certain extent the activation of phonology in Chinese character recognition is affected by task demands. Phonology is strongly activated whenever vocal responses are involved. But when only manual responses are required, phonological activation is weak. So, phonological activation in Chinese character recognition is task-dependent. However, based on the same results one might argue that in all cases phonology is activated and, hence, the activation of phonology is nonoptional. The nonsignificant difference of homophone effects between the button-pressing task and the mixed task may imply that both tasks have low sensitivities to phonological effects. In contrast, naming in a Stroop task may be more vulnerable to the influences of phonology. Therefore, a homophone effect was found in the naming task. Although the latter explanation is possible, we believe that it is not very likely for the reasons discussed in Experiment 4. A third possible explanation is that both task demand and response sensitivity are responsible for the pattern of results obtained in the present studies. The following discussions are focused on the third interpretation.

Using a backward priming task, Perfetti and Zhang (1991) found that phonological activation in Chinese character recognition was nonoptional. Because a word naming task was used in the experiment where the phonological effect was found in Perfetti and Zhang's study, the finding is consistent with those obtained with the naming task in Experiment 3. Actually, the evidence for obligatory activation of phonology in the present studies is even stronger than that in Perfetti and Zhang's study. The reason is that, in Experiment 3, the phonology of the words never provided information that could facilitate position naming; rather it consistently harmed performance. Nevertheless, phonological activation could not be suppressed entirely and Stroop interference with homophones resulted. Thus, phonological activation seems to be obligatory. However, when the task required simply button-pressing (Experiment 2), the phonological effect was much smaller which indicates that phonological activation is somewhat under strategic control. The seemingly contradictory implications of these results may be accounted for by assuming that automaticity is a continuum rather than an all-or-none phenomenon (MacLeod & Dunbar, 1988). With the continuous automaticity view, a strongly automatic process cannot be affected by other processes, but a weakly automatic process can be modulated by certain factors. Thus, it is hypothesized that the use of phonology in Chinese character recognition is a weakly automatic process that can be affected by task demands, but is not under total strategic control.

The results from the present study do not support the view that word recognition is exclusively mediated by phonology (Perfetti & Zhang, 1991; Van Orden et al., 1988), nor do the results support the view that phonological activation is entirely optional and occurs only when it is beneficial to the performance (Brysbaert & Praet, 1992; Coltheart, 1978). Instead, the results are consistent with a dual-route view in which both orthographic and phonological activation contribute to the access of meaning (Jared & Seidenberg, 1991; Seidenberg and McClelland,1989). The fact that the extent to which phonology is activated depends on the task demands can be explained in terms of the relative use of orthographic and phonological information in different tasks. We will use Seidenberg and McClelland (1989) model for word recognition, and Cohen, Dunbar and McClelland (1990) model for Stroop task to develop this idea.

In the connectionist version of dual-route model proposed by Seidenberg and McClelland (1989), words are assumed to be represented by pattern of activation distributed over units. Processing occurs by the spread of activation along pathways of different strength. The activation of orthographic representations happens first and, then, spreads directly to the phonological units, as well as directly to the semantic units. There is also a secondary spread of activation from phonological units to semantic units. Thus, the semantic representation of a word is activated by the two sources of activation. There can be partial activation of representations; thus, orthographic input can partially activate phonological representation and semantic representation; and activation of phonology in turn can partially activate semantic representations. Generally, the two routes (or pathways) are activated in parallel and jointly contribute to the activation of semantic representation. Now, the questions are: To what extent are the two sources of activation used in word recognition process? What are the factors that could affect the relative use of the two routes (or pathways)? How are the orthographic and phonological routes related to each other in skilled normal reading? The general consensus regarding these questions is that low-skilled readers make more use of phonology (Doctor & Coltheart, 1980; Rusted, 1989); female readers may rely on phonological information more often than male reader (Naish, 1980); phonology plays fundamental role in the identification of low frequency words (Jared & Seidenberg, 1991; Seidenberg, 1985); and phonological representations usually get activated when the context of the stimuli is favorable for the incorporation of phonological information (Brysbaert & Praet, 1992; Davelaar, et al, 1978). The results from the present study suggest that task demand might be another possible factor that affects the relative use of orthographic and phonological information in word recognition.

However, the exact mechanism of adjusting the relative use of the two sources of activation is not explicit in Seidenberg and McClelland's model. The task-dependent effect may be accounted for by introducing task demand as an attentional mechanism that modulates level of activation in orthographic, phonological and articulatory pathways. It has been proposed, in a parallel distributed processing model for the Stroop task (Cohen et al., 1990), that task demand is similar to attention; both serve as additional inputs that modulate the operation of processing units in a pathway. When a particular task is required, the additional input from the task demand increases the level of activation in a pathway that is related to that task. We assume that, in a task involving vocal response, articulatory information comes from both semantic and phonological representations. Semantic representation is assumed to contain motor commands for articulation. Phonological representation of a word is assumed to share features with the articulatory phonology of that word. Thus, the activation of phonology and meaning facilitates the articulation of the word. On the other hand, if the activated phonology or meaning conflicts with the desired vocal response, then the activation of phonology or meaning interferes with the articulation. As a task demand, vocal response requirement enhances the level of activation in phonological and articulatory pathway. Consequently, the activation of phonology is stronger in a vocal task than that in a non-vocal task. In other words, readers may make much use of phonology relative to orthography in oral reading, but may make little or no use of phonology relative to orthography in silent reading. When the phonological effect is measured on trials of vocal responses, an additional effect may be found because of the direct relatedness between phonology and articulation.

In the present studies, when the task involved position naming, vocal response requirement as an additional input enhanced the level of activation in phonological and articulatory pathway. Consequently, the strong activation of phonology from homophones caused an observable interference effect. In the case of button-pressing, no task demand input was added to the phonological pathway. Thus, the system was adjusted to use little of the phonological pathway comparing with the orthographic pathway. The activation of phonology was weak, and resulted in a barely detectable interference effect for homophones. In the mixed task, subjects did not know what kind of response (button-pressing or naming) they should make for each trial until the character was identified. Prior to the identification of the word, the best strategy would be to get ready to response in both ways. Subjects paid attention to at least three dimensions of the stimulus. First, in order to decide what kind of response they should make, subjects had to know whether the stimulus is an orientation word or not. Because this process involved a semantic judgment, subjects needed to attend to the semantic content of the word. Second, if the word was an orientation word, a manual position response had to be made. To accomplish this goal, subjects had to pay attention to the spatial relation between the word and the asterisk. Finally, when the stimulus was not an orientation word, subjects read the word aloud; thus they had to attend to the phonological information of the word as well. Getting ready to make a vocal response entailed an additional input to the phonological and articulatory pathway, which increased the activation of phonological information. Therefore, interference effects for both position words and homophones resulted. Although the homophone effects for naming task and mixed task were not statistically different, the effect for naming was numerically bigger than that for mixed task. The homophone effect for mixed task was measured on button-pressing trials, whereas the effect for naming task was measured on naming trials. Therefore, the possible additional effect for naming task may due to the high sensitivity of vocal response to the influences of phonology.

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Appendix A

Chinese Character Stimuli.

stimulus type	character	meaning	Pronunciation in Cantonese	Pronunciation in Madarin
Position word	[illegible]	[illegible]ove	seuhng	shang
	下	below	hah	xia
	左	left	jo'	zuo
	右	right	yauh	you
homophone	尚	still	seuhng	shang
	夏	summer	hah	xia
	阻	hinder	jo'	zu
	幼	young	yauh	you
graphic similar	土	soil	to'u	tu
	不	no	ba'	bu
	在	on	tsai	zai
	石	stone	sehk	shi
semantic similar	高	high	go'u	gao
	低	low	dai'	di

	西	west	sa'i	xi
	东	east	dung	dong
control I	白	white	baahk	bai
	去	go	heui	qu
	五	five	ng'h	wu
	毛	fur	mo'uh	mao
control II	原	origin	yu'hn	yuan
	明	bright	mi'hng	ming
	生	raw	sa'ang	sheng
	用	use	yuhng	yong
orientation word	北	north	ba'k	bei
	南	south	na'ahm	nan
	西	west	sa'i	xi
	东	east	dung	dong

Appendix B

Mean Response Times (in Milliseconds) for Each of the Position Words, Homophones, Graphically Similar Words, Phonologically Similar Words and Controls in Experiment 1.

Character		Response times
Position word	left	668
	above	680
	right	644
	below	672
Homophone	hinder	669
	still	653
	young	661
	summer	636
Graphically similar word	on	656
	soil	643
	stone	650
	no	646
Semantically similar word	west	652

	high	652
	east	669
	low	663
Control 1	five	650
	white	625
	fur	647
	go	676
Control 2	raw	652
	use	638
	origin	639
	bright	640

Appendix C

Mean Response Times (in Milliseconds) for Each of the Position Words, Homophones and Controls in Experiment 2.

Character		Response times
Position word	above	959
	right	918
	below	988
Homophone	still	752
	young	728
	summer	815
Control 1	white	792
	fur	762
	go	767
Control 2	use	739
	origin	755
	bright	765

Appendix D

Mean Response Times (in Milliseconds) for Each of the Position Words, Homophones and Controls in Experiment 3.

Character		Response times
Position word	above	1070
	right	1078
	below	1065
Homophone	still	951
	young	827
	summer	944
Control 1	white	872
	fur	831
	go	855
Control 2	use	847
	origin	832
	bright	851

Appendix E

Mean Response Times (in Milliseconds) for Each of the Position Words, Homophones and Controls in Experiment 4.

Character		Response times
Position word	above	801
	right	804
	below	825
Homophone	still	681
	young	682
	summer	752
Control 1	white	697
	fur	676
	go	677
Control 2	use	678
	origin	682
	bright	672