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When dough is a female deer: The role of homophony in lexical priming

Kevin Kyle Fleming
University of New Hampshire, Durham

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Fleming, Kevin Kyle, Ph.D.

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U·M·I
300 N. Zeeb Rd.
Ann Arbor, MI 48106

WHEN DOUGH IS A FEMALE DEER: THE ROLE OF HOMOPHONY IN LEXICAL PRIMING

BY

KEVIN K. FLEMING

B.A. Lehigh University, 1985

M.A. University of New Hampshire, 1987

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This dissertation has been examined and approved.

Dissertation director,
John Limber,
Associate Professor of Psychology

Victor Benassi,
Associate Professor of Psychology

Grant Cioffi,
Associate Professor of Education

Albrecht Inhoff,
Associate Professor of Psychology at SUNY, Binghamton

Edward O'Brien,
Assistant Professor of Psychology

Dan Swift,
Associate Professor of Psychology at the University of Michigan, Dearborn

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ABSTRACT

WHEN DOUGH IS A FEMALE DEER: THE ROLE OF HOMOPHONY IN LEXICAL PRIMING

by

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Several models of printed word recognition claim that phonology mediates lexical access. Four experiments employing lexical decision tasks and naming tasks were conducted to assess this claim. Homonyms such as "mint" were used in Experiment 1 to verify that both meanings of an ambiguous word are activated automatically upon presentation. In a priming paradigm with a 250 millisecond SOA, the homonym "mint" was found to facilitate the recognition of words related to both interpretations such as "candy" and "coin." In the remaining three experiments, homophones such as "dough" and "doe" were used to assess the role of phonology in lexical priming. Experiment 2 examined the priming effects of visually presented homophone primes (e.g., "dough") upon responses to a target word that was either semantically related to the prime (e.g., "bread") or mediated by the phonological code for the prime (e.g., "deer"). Priming effects were found for targets that were semantically related to the prime, but not for targets that were mediated by a phonological code. In Experiment 3, the homophone (e.g., "dough") served as the target and the prime was either semantically related (e.g., "bread") or mediated by a phonological code (e.g., "deer"). In the lexical decision task, priming effects were observed when the prime was semantically related, but not when the prime was mediated by a phonological code. However, in the naming task, priming effects were observed when the prime was mediated by a phonological code. In the last experiment, the homophone (e.g., "dough") again served as a prime, but it was made ambiguous by auditory presentation. Priming effects were evident for both interpretations of the ambiguous word in both lexical decision and naming. These results indicate that phonology plays a role in lexical access when the homophone is presented auditorily, and when the homophone must be pronounced; but phonology does not appear to play a role in lexical access when the homophone is presented visually, or when the response does not involve pronunciation. These results suggest a limitation on the role of phonology in models of printed word recognition.

INTRODUCTION

Overview

Before learning to read at around five years of age, children have already accumulated a vocabulary of several thousand words. Because most of a child's early exposure to language comes from spoken communication, it is evident that reading skills are built upon the foundation of listening and speaking skills. Accordingly, children are often taught to sound out words when they are learning to read. With practice, children become fluent enough to read without actually talking to themselves, but this doesn't mean that they no longer sound out the words covertly. Even as adults we seem to read silently to ourselves. Sometimes it is even possible to hear the words in our mind's ear as if they were being read to us in our own voice or in the voice of the person who wrote the text.

Observations such as these have caused reading researchers to ask whether the covert conversion of written text to sound patterns or even sub-vocal speech patterns is a prerequisite for lexical access, or whether it is simply a vestigial feature of reading skill acquisition. It is the purpose of the present investigation to address such questions as these within the limited realm of word recognition and lexical priming effects.

In particular, it will be asked whether a homophone such as "dough" will facilitate or "prime" the recognition of a word such as "deer." It is clear that "doe" will prime the recognition of "deer," but it is not clear whether "dough" will have the same effect. Homophones such as these share the same phonological code, but do not share the same orthographic code. If it is found that "dough" primes the word "deer," then the priming effect must be mediated by a phonological code, a process that will be referred to as phonologically mediated priming.

In the remaining sections of this introduction, I will discuss several models of word recognition, some of which predict phonologically mediated priming and some of which do not. I will then present several lines of investigation that have sought to demonstrate the effects of phonology in word recognition; effects such as homophone substitution and rhyme priming. In the final section, I will outline several types of priming including multiple semantic priming and phonologically mediated priming. I will then conclude by presenting the logic behind the design of the series of studies to follow.

Theories of Lexical Access

The prevailing model of the lexicon is that of a semantic network (Quillian, 1966; Collins & Quillian, 1969; Collins & Loftus,1975). Each word occupies a node in this network and is connected to other nodes via associative links which are primarily semantic in nature. When a word is seen or heard, its node becomes active and this activation spreads to other nodes along the existing links in the network. This "spreading activation" model provides a fruitful description of semantic priming effects in which a word such as "bread" is recognized more quickly when it is preceded by a semantically related word such as "dough" than when it is preceded by a semantically unrelated word such as "pearl."

The relationship between "dough" and "bread" is semantic in nature, but semantic links are not the only associative links that are possible in a spreading activation model. Orthographic and phonological links are also possible. An example of an orthographic link would be the link between the words "break" and "bread." These two words share many letters in common but relatively few phonemes. An example of a phonological link would be the link between the words "eight" and "late." These two words share many phonemes in common but relatively few letters. As these two examples illustrate, nodes in the lexicon may be connected by links other than semantic links.

The preceding discussion has centered around the lexicon itself and how activation may spread within it. But the problem remains as to how spoken and printed words cause lexical nodes to become active in the first place. This is the problem of lexical access and over the past three decades several solutions have been proposed. In this section, I will discuss these models of lexical access and present their predictions concerning phonologically mediated priming. In order, the models of printed word recognition that I will discuss include a direct orthographic route model, an indirect phonological route model, a dual-route model, and an interactive-activation model.

Despite the steady accumulation of empirical research over the past several decades, no consensus has been reached concerning which model of lexical access, if any, most accurately represents the facts (Humphreys & Evett, 1985; Foss, 1988; Seidenberg & McClelland, 1989; Pollatsek & Rayner, 1989). This failure to reach a consensus is due primarily to the complexity of the processes underlying word recognition, the subtle differences in the models, and the lack of empirical methods that are sensitive enough to reveal these differences.

Direct Orthographic Route

Any model of printed word recognition must begin with an account of how the visual system transduces the electromagnetic radiation reflected by a few slashes of ink on paper into a pattern of neural activity within the brain. Although the low-level activities of the cells along the visual pathway are not trivial, I will jump ahead to the so-called "simple" and "complex" cells of the visual cortex identified by Hubel and Wiesel (1959). Simple cells in layer IV of the striate cortex of the cat respond selectively to lines and bars of specific orientations. Complex cells receive input from simple cells and respond to higher level properties of lines and bars such as length, width, and directional movement. Clearly cells in the cortex of the cat respond to highly specific properties of stimuli. A complete description of word recognition, however, cannot be found in our current understanding of the nervous system. It is therefore necessary to construct theories about the representations and processes that must exist in any system capable of word recognition.

The diagram in Figure 1 presents a model of lexical access involving a direct orthographic route. A printed word such as "dough" is encoded by the visual system in terms of its orthography. For the word "dough," the orthography can be represented as "d-o-u-g-h." This orthographic code then directly activates the concept of "dough" in the lexicon. The process by which the orthographic access code activates the concept node may involve template matching or feature analysis. But for any of these processes to be successful, the concept node in the lexicon must contain a matching orthographic representation that is definitive and yet not so specific that variations in typeface or handwriting cannot activate the concept. Once a "match" to the concept node "dough" is achieved, activation will spread to semantically associated concept nodes such as "bread," "yeast," and "flour."

The orthographic route to the lexicon is described as "direct" because lexical access requires orthographic representations only. The physical stimulus is encoded visually in the form of an orthographic code and the concept node within the lexicon contains an orthographic code that then "matches" the visual input. Activation of the concept node in the lexicon will therefore be achieved on the basis of orthographic information alone.

If lexical access relies solely upon orthographic information, then what is the role of phonology in reading? As presented, the model does not allow phonology to play any role in reading. This, however, does not mean that

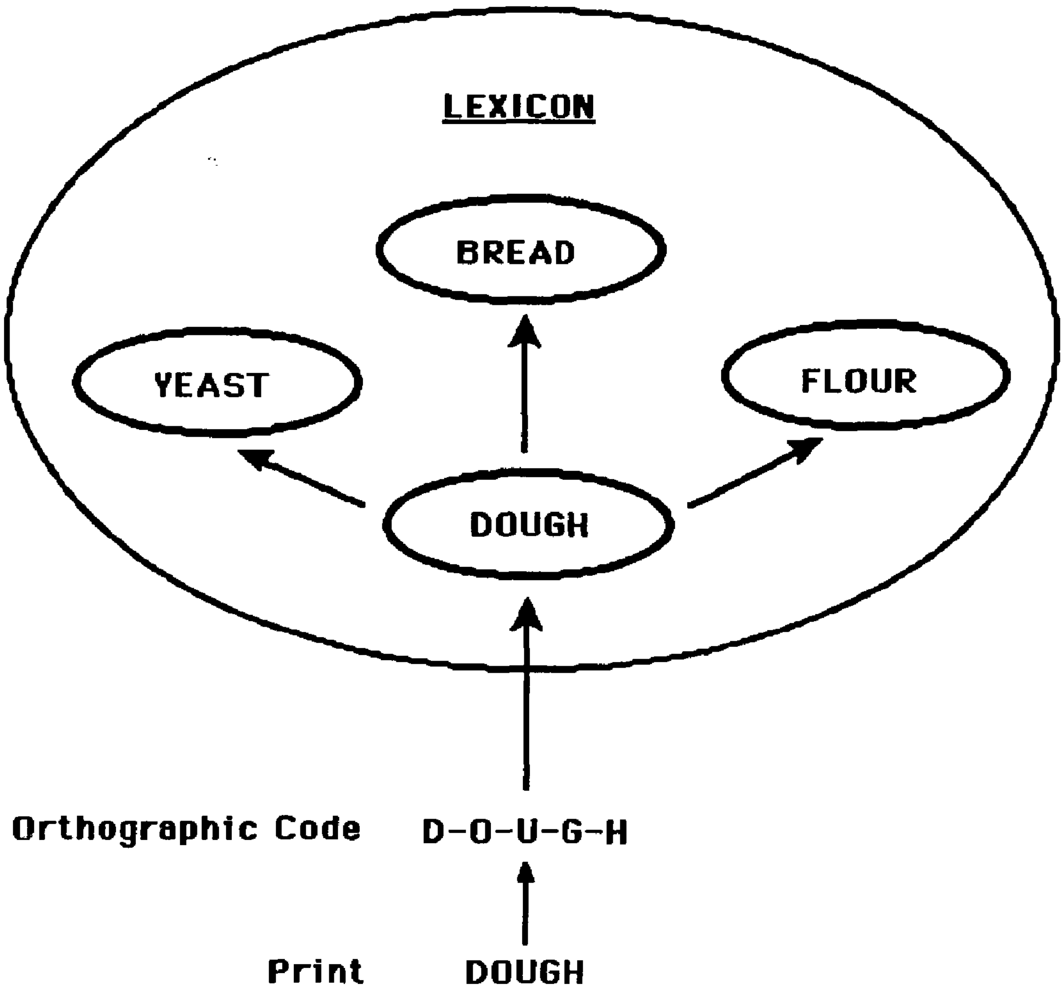

Figure 1. A model of lexical access involving a direct orthographic route.

phonology is completely absent from lexical processing. Obviously, phonology must be involved in both the recognition of spoken words and the pronunciation of printed words. The present model simply provides no role for phonology during the recognition of printed words. Furthermore, because phonology plays no role in lexical access, the direct orthographic route model does not predict phonologically mediated priming. If the printed word "dough" only activates the lexical item "dough," then priming will not occur for the lexical item "deer."

These are strong claims, but the notion that lexical access involves an orthographic code has never been seriously questioned by researchers interested in visual word recognition (Morton, 1969; Bower, 1970; Forster, 1978; McClelland & Rumelhart, 1981). It is quite clear that the visual system is involved in the early stages of word identification, and it is also true that most models of the later stages of word identification propose a variety of orthographic codes including templates, features, graphemes, and logogens. However, the conclusion that printed word recognition involves only orthographic codes may obscure the role of phonological codes. What are we to make of the fact that the English language employs a phonetic alphabet? How are we able to pronounce words that we have never seen before such as "rowel," or even non-words such as "blark?" How do we learn to read new words in the first place?

A model of word recognition that relies only upon orthographic codes appears to be unable to account for our ability to pronounce unfamiliar words and/or non-words because no rules are supplied for converting the orthographic code into a phonological code. There is no problem for the model when it comes to pronouncing familiar words because we can assume that the rules for their pronunciation are to be found in the lexical entry. But, when it comes to words that are not in the lexicon, no separate rules for pronunciation are available. This creates a problem when we are faced with a new word that we have never seen before, such as "rowel." We can encode the word "rowel" as the orthographic code, "r-o-w-e-l," and we can encode the meaning of "rowel" as "the spiked wheel at the base of a spur," but unless there are some rules for generating a plausible phonological code we will not be able to say /rowel/. This would indeed be a peculiar problem when reading aloud, but it is intriguing to note that certain dyslexics identified as "phonological alexics" cannot pronounce non-words (Morton & Patterson, 1980). Apparently, these dyslexics have lost the rules that would allow them to pronounce unfamiliar letter strings. This indicates that some means for generating phonological codes for printed words must exist and therefore may play some role in lexical access. Before describing several models of lexical access that do involve phonology, however, I would like to describe a modification of the direct orthographic route model that provides an account for phonologically mediated priming.

With some modifications at the level of the lexicon, the direct orthographic route model can accommodate phonologically mediated priming effects and yet retain direct orthographic lexical access. If the activation of a concept node is allowed to spread to other concept nodes sharing the same phonological code, then activation from the concept node "dough" may spread to the concept node "doe" via the phonological code /dō/. Figure 2 shows how the spread of activation following the presentation of the printed word "dough" will result in the activation of the concepts for both "bread" and "deer." In this way, a model having direct orthographic lexical access can provide an account for phonologically mediated priming effects. The priming in this model, however, is referred to as "post-lexical" because the phonological code for the word is only activated once its lexical entry has been activated.

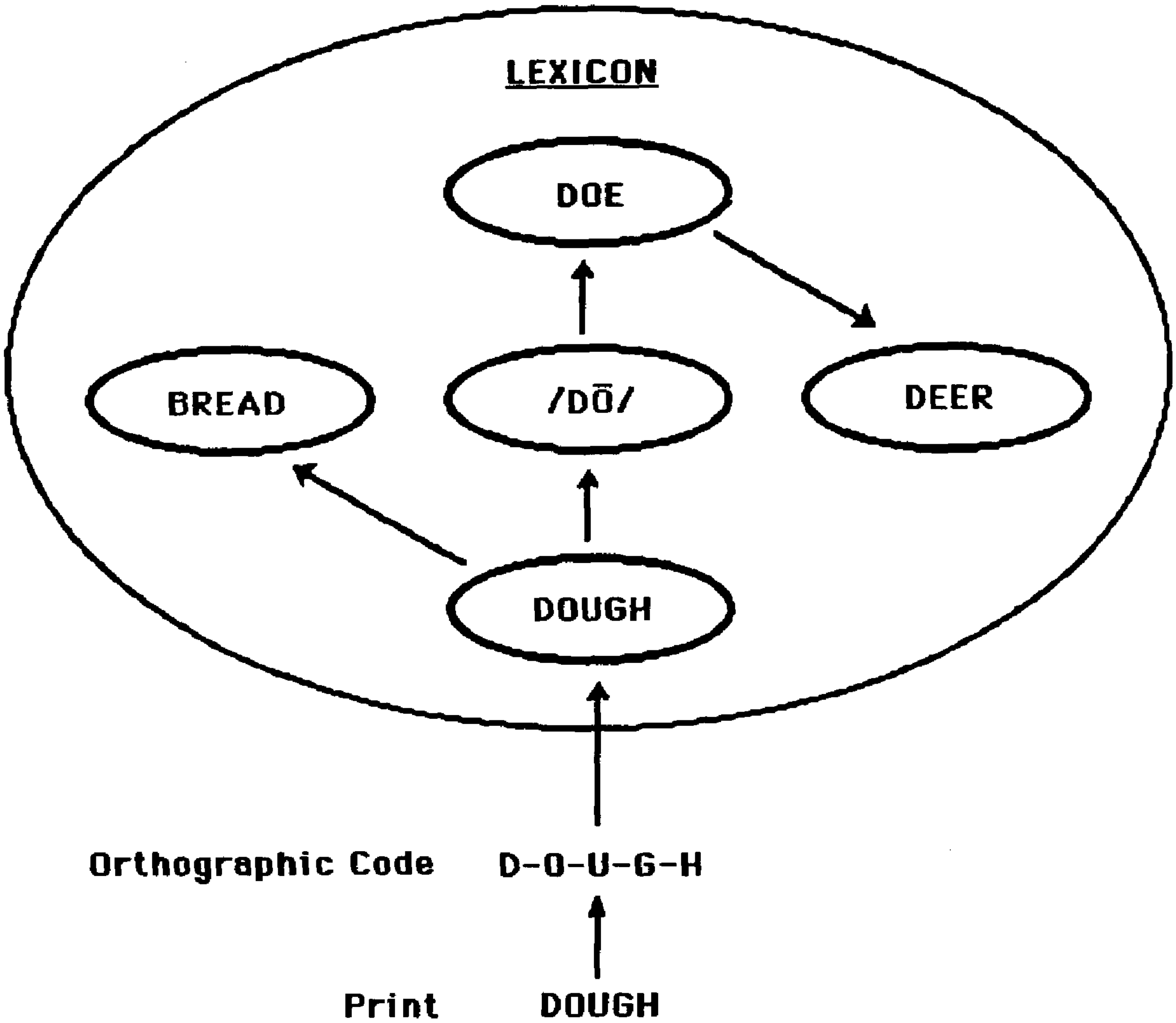

Figure 2. A model of lexical access involving a direct orthographic route and post-lexical activation of phonological representations.

Unfortunately, like its parent model, the modified model does not explain how unfamiliar words are activated in the first place, or how non-words can be pronounced without any rules for pronunciation outside of the lexicon.

Indirect Phonological Route

If the letters of the alphabet specify (to some extent) phonemes which allow for the rapid conversion of print into speech, then it seems plausible to propose that phonological codes also play a role in lexical access. One model that allows phonology to play a role in lexical access involves an indirect phonological route to the lexicon. According to the strong form of this model presented in Figure 3, the lexicon contains only the phonological code for each lexical item. This means that visually presented words must be converted into a phonological code prior to lexical access.

Lexical access involving the phonological route is referred to as "indirect" and "pre-lexical" because an additional stage of processing is required prior to lexical access. The indirect phonological route takes advantage of the phonetic features of the alphabet in order to generate a plausible phonological code for any string of letters. The rules for generating the phonological code are referred to as "grapheme-phoneme correspondence" rules, or GPC rules. Having GPC rules allows for the pronunciation of unfamiliar words as well as non-words for which no lexical entry exists.

Examination of the model in Figure 3 reveals that phonological recoding via GPC rules prior to lexical access predicts the activation of all words having the same phonological code. Phonologically mediated priming would therefore be predicted by this model because the phonological code for "dough" is the same as that for "doe." Visual presentation of the word "dough" will thus activate both of these homophones in the lexicon along with their semantic associates "bread" and "deer." In fact, discrimination between "doe" and

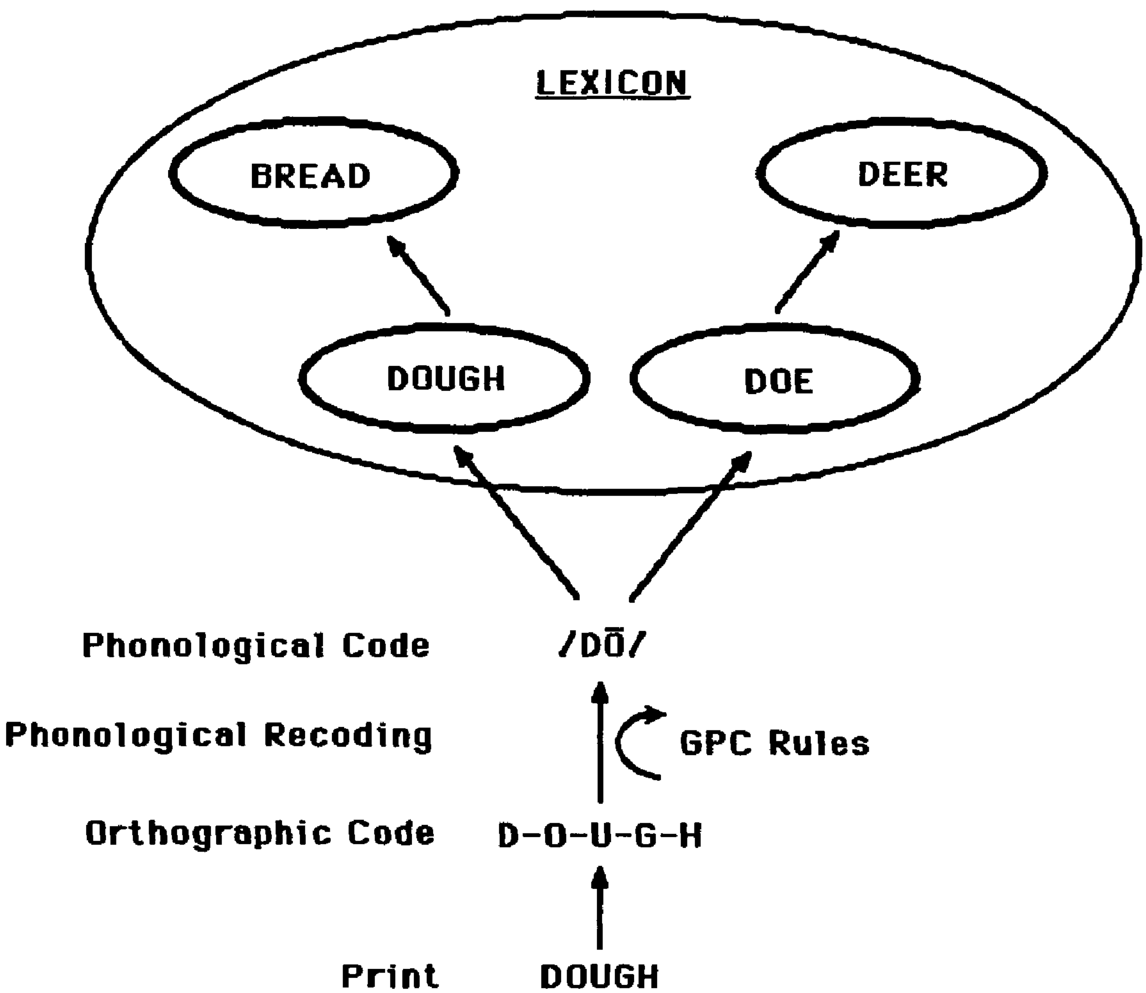

Figure 3. A model of lexical access involving an indirect phonological route.

"dough" is not possible at the lexical level, and equal levels of activation would be predicted for each homophone (barring any differences in other variables such as word frequency). This would result in homophone substitution errors in which the presentation of the word "dough" leads to an erroneous interpretation such as "a female deer."

It may appear that indirect access is less parsimonious than direct access because it involves an extra stage of processing. However, the parsimony that is lost at the pre-lexical recoding stage is regained at the lexical level because only the phonological codes for words need to be stored in the lexicon. Once the phonological code for a word has been generated, the processes involved in printed word recognition could then "piggyback" on the existing processes involved in spoken word recognition. In extreme form, reading would quite literally involve speaking silently to oneself.

Issues of parsimony are often misleading, however, because the parsimony that is gained by having only phonological codes in the lexicon will later be lost when it comes time to write. Additional rules would have to exist outside of the lexicon for converting the phonological code into a pattern of letters. To the extent that English phonology does not map perfectly onto its orthography, the spelling of even the best reader would be poor unless some information about the orthography of each word was retained.

The same criticism holds true for the GPC rules involved in lexical access and pronunciation: To the extent that orthography does not map precisely onto phonology, irregular English words such as "pint" which do not follow the regular rules of pronunciation (i.e., "lint," "mint," and "print") will be pronounced incorrectly. Furthermore, the recognition of irregular words will also fail if lexical access is mediated solely by GPC rules because there is no entry in the lexicon which "matches" the phonological code for "pint" when it is recoded like "mint."

The English language may employ a phonetic alphabet, but this does not mean that English phonology maps precisely onto orthography. A range of possible sounds will correspond to any given string of letters in the English language, and these sounds may or may not correspond to actual words. Just as it seems erroneous to claim that lexical access can be accomplished only via an orthographic code, so it also seems erroneous to claim that lexical access can be accomplished only via a phonological code. If both codes are available, and if neither code alone is sufficient, then both codes ought to be utilized.

Dual-Route Model

The dual-route model of lexical access is perhaps the most commonly accepted model (Morton, 1981; McCusker, Hillinger, & Bias, 1981; Humphreys & Evett, 1985). Figure 4 presents a diagram of the dual-route model. One route to the lexicon is through a direct orthographic route. This route allows for the direct activation of lexical items through orthography so that irregular words like "pint" can be accessed and pronounced correctly. Another route to the lexicon is through an indirect phonological route. This second route allows for the generation of a plausible phonological code for non-words such as "bint," the pronunciation of which will probably be similar to the regular word "mint." It also allows for the recognition of printed words that have been heard before but never actually seen, as in the case of children who already know what many words sound like, but have never seen them.

The dual-route model is also supported by neurological evidence (Morton & Patterson, 1980; Patterson & Morton, 1985). Selective impairment of the direct orthographic route leads to a form of dyslexia called "surface dyslexia." Patients suffering from surface dyslexia can easily pronounce regular words and non-words, but they tend to regularize the pronunciation of irregular words like "island," pronouncing it as /iz-land/. This indicates that the indirect

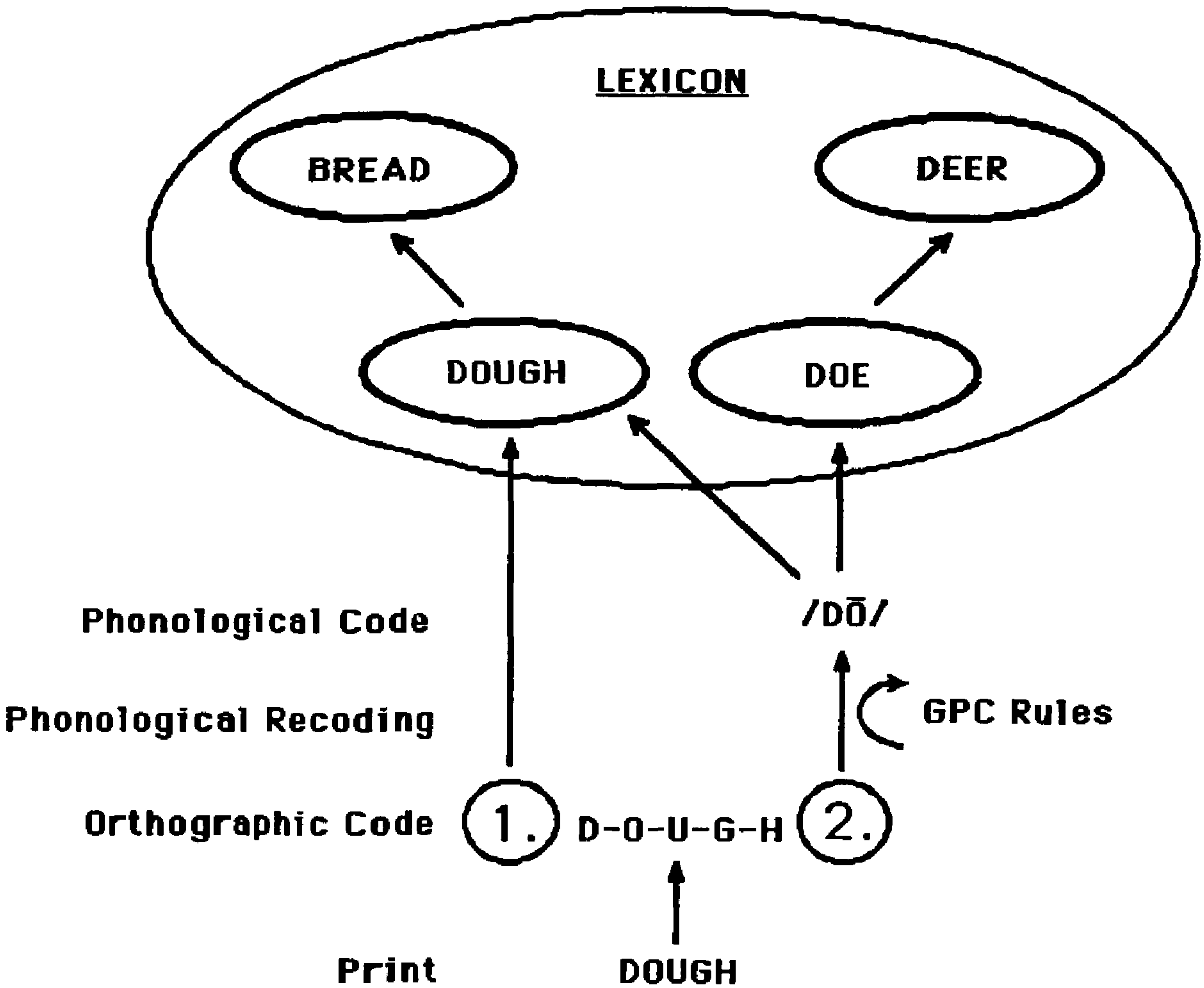

Figure 4. A dual-route model of lexical access.

phonological route appears to be intact in these patients, but that the direct orthographic route has been selectively damaged. It is important to note that prior to their lesions, these patients had no difficulty pronouncing irregular words. Another form of dyslexia, "phonological alexia," appears to selectively impair the indirect phonological route. These patients can pronounce both regular and irregular words, but they cannot pronounce non-words. This suggests that the lexical phonology for words remains intact in these patients, but that the GPC rules for converting print into sound are impaired.

Examination of Figure 4 reveals that the dual-route model predicts phonologically mediated priming. Following the visual presentation of the word "dough," the indirect phonological route will activate both "doe" and "dough." The direct orthographic route, however, will activate only "dough." If both of these routes to the lexicon operate in parallel, at the same speed and strength, then the lexical entry "dough" will receive activation from both routes and the lexical entry "doe" will receive activation from only the indirect phonological route. Given this disparity, priming for both "bread" and "deer" would be predicted, but the effects would be stronger for the word "bread," all other things being equal.

Interactive-Activation Model

One final model that has recently been advanced to describe lexical access is an interactive-activation or "connectionist" model. Early versions of the model involved only orthographic codes (McClelland & Rumelhart, 1981), but more recent models have incorporated phonological codes as well (Seidenberg & McClelland, 1989). A diagram depicting an interactive-activation model appears in Figure 5. The first thing that is apparent in this model is that there is no lexicon that separates the concept nodes from the orthographic and phonological units that activate them. In fact, all of the units

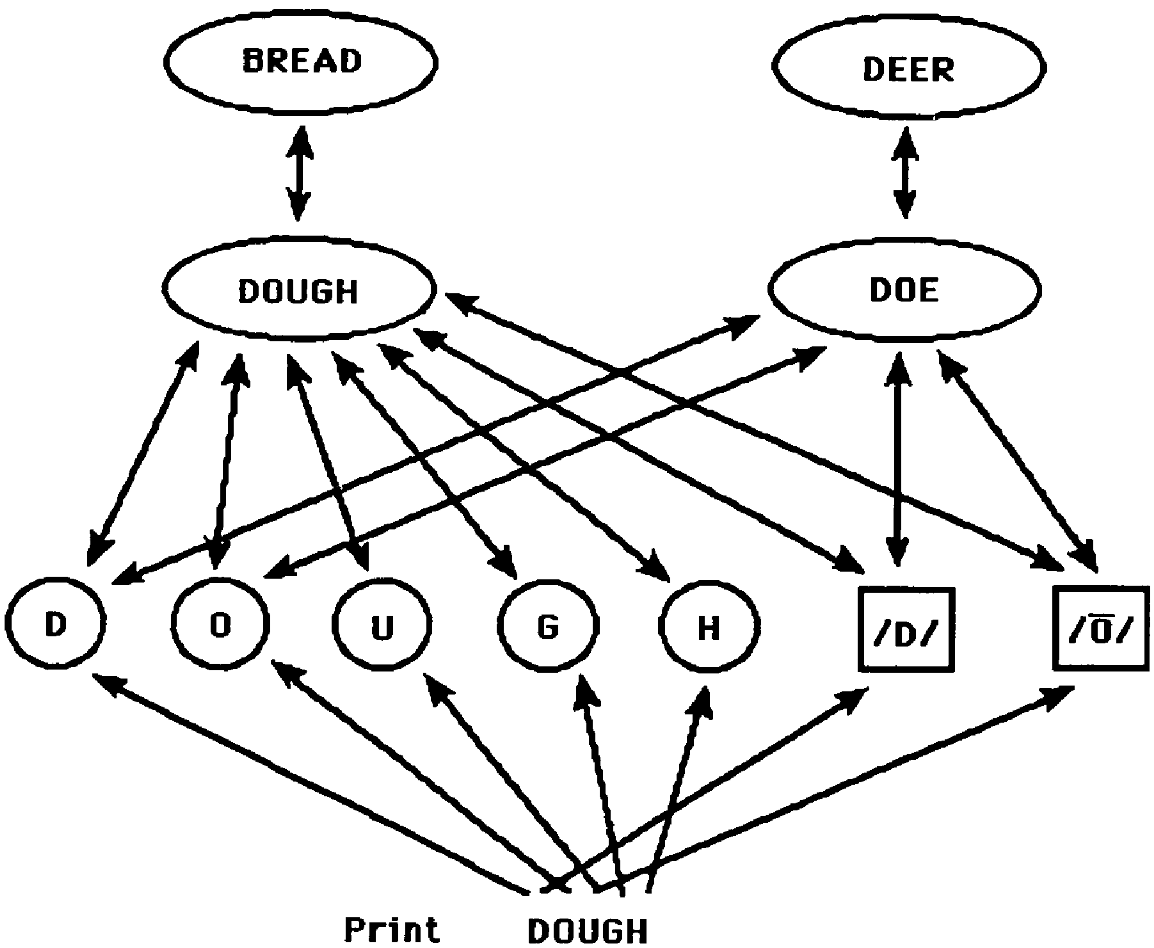

Figure 5. An interactive-activation model of lexical access.

are part of a vast network; each unit interacting with every other unit to a greater of lesser degree.

The interactive-activation model as presented by Seidenberg and McClelland (1989) predicts phonologically mediated priming. Examination of the diagram in Figure 5 reveals that the presentation of the word "dough" will activate all of the orthographic and phonological units that compose the printed word. These units in turn activate (interactively) concept units sharing these orthographic and phonological features. The concept "dough" will receive the most activation because it shares most of the features. But the concept "doe" will also receive activation because it shares all of the phonological features and a few of the orthographic features. These concept units will then activate semantically associated concept units. Thus the printed word "dough" will prime "bread" quite strongly and "deer" less strongly, all other things being equal. In fact, the interactive-activation model predicts the same phonologically mediated priming effects as the dual-route model.

The dual-route model and the interactive-activation model both predict strong semantic priming effects from "dough" to "bread," and relatively weak phonologically mediated priming effects from "dough" to "deer." But what does it mean to find a "relatively weak" effect? The usual F-ratio statistics may be larger or smaller depending upon the size of the effect, but when they are used to simply accept or reject a null hypothesis, the relative size of the effect is no longer of interest.

One way to obtain information about the relative size of an effect is to calculate an "effect size." Rosenthal (1984) presents several ways in which the effect size can be calculated, but he favors the use of the statistic, r, which represents the square root of the variance accounted for by the independent variable of interest. The r statistic is also better known as Pearson's productmoment correlation coefficient and it can vary between - 1 and + 1. This statistic is especially suited to the evaluation of priming effects because positive values of *r* can represent facilitation and negative values can represent inhibition. Furthermore, the *r* statistic can provide information about the relative strengths of these effects. If we predict a relatively weak effect from a certain manipulation, it is thus possible to look for a small effect size.

The results of the present investigation will be analyzed using effect sizes as well as significance tests in order to provide a more complete description of the phenomena under investigation. When we ask whether priming is mediated by a phonological code, we are not asking an all-or-none question; rather we are asking how much of an effect phonology exerts during priming relative to orthography. Given the suitability of *r* as a measure of the magnitude and direction of a priming effect, it is surprising that it has not become common practice in the priming literature to report the effect size. As we shall see in the coming section, the failure to report effect sizes has also made it difficult to draw conclusions from the array of studies that have sought to demonstrate effects of phonology on word recognition.

Lines of Empirical Investigation

Having discussed several current models of lexical access and their predictions regarding phonologically mediated priming, we are now in a position to evaluate the empirical evidence concerning the role of phonology in word recognition. All of the models presented except the direct orthographic route model in Figure 1 posit a definite role for phonology in word recognition. The central issue however is not whether phonology plays a part in reading after the meaning of a word has been activated: The issue is whether phonology is involved in the access of word meanings. Each study must be evaluated in light of whether it provides convincing evidence that phonology is involved in the access of word meanings. Seidenberg and McClelland (1989) have made this point succinctly:

> "Many studies have provided evidence that subjects use phonological information in reading, but ... this fact does not itself necessarily indicate that access of meaning was phonologically mediated. In general, it has proven difficult to empirically discriminate between activation of phonological information and phonologically mediated access of meaning."

Homophone Substitution Effects

A sentence chosen at random from a popular novel reads "Their way wound along the floor of the hollow, and round the green feet of a steep hill..." (Tolkien, 1965, page 189). A reader would probably find nothing unusual about this sentence because there is actually nothing wrong with it. What is remarkable, however, is that an ordinary sentence such as this is laden with problems for any system designed to extract pronunciation and meaning from printed words. The first two words are homophones and the third word is a homograph. If you automatically convert print to sound, why does the word "way" conjure up the concept "path" and not the concept "weigh?" Moreover, if you had to read this sentence aloud, why would you pronounce the word "wound" as /wownd/ and not /woond/? These are just some the potential problems you face when reading text, and it is remarkable that difficulties of this sort do not arise more frequently than they do.

Several studies have investigated the role of phonology in reading by substituting inappropriate homophones into sentences and asking subjects to indicate whether anything is wrong. Baron (1973) created sentences of the form "Tie the not." He found that subjects required no more time to reject sentences with homophone substitutions than they did to reject sentences of the form "Tie the know." Baron predicted that it would take longer for subjects to reject homophone substitutions because the computed phonology for "not" would activate the correct homophone "knot" and, in order for subjects to respond correctly to these sentences, they would have to run an additional spelling check that would increase the amount of time required to respond "no." On the basis of this result, Baron concluded that phonology did not play a role in reading. A closer look at Baron's (1973) results suggests, however, that people are influenced by phonology when they read.

First, the reaction time data is in the appropriate direction even though the difference is not significant. Perhaps if the power of the study was increased with more subjects and/or more stimuli, the effect would be significant. Baron's study illustrates a problem that must be considered in any attempt to demonstrate that phonology does not play a role in lexical access; namely, that accepting the null hypothesis cannot constitute conclusive evidence for the absence of an effect. As a consequence, the null hypothesis that phonology plays no role in lexical access can never be proven; it can only be shown that the size of the effect is minimal.

A second problem with Baron's conclusion is that subjects made almost twice as many errors for homophone substitutions; an effect that upon retrospective analysis proved significant. This result is actually evidence in support of the role of phonology in lexical access. I will refer to this result as the homophone substitution effect.

Later studies similar in design to Baron (1973) have replicated the homophone substitution effect for adults as well as children. Doctor and Coltheart (1980) presented children ages 6 to 10 sentences like "She blue up the balloon." They found that 6 year old children failed to reject these sentences over 70 percent of the time, and that the magnitude of this effect declined among older children to about 20 percent. The decline in the effect was probably due to increased knowledge of spelling among the older children, but it is important to note that the children in all age groups were able to discriminate between homophones like "blue" and "blew."

More recently, Coltheart, Laxon, Rickard, and Elton (1988) demonstrated the homophone substitution effect among adults. They presented sentences like "The girl through the ball" and found that subjects failed to reject such sentences 16 percent of the time as compared to only 6 percent of the time for control sentences (e.g., "The girl thought the ball.").

In another series of studies, homophone substitution effects were observed in a category verification task (VanOrden,1987; VanOrden, Johnston & Hale,1988). Subjects were presented a category such as "a type of deer" followed by a target word. They were instructed to say "yes" as quickly as possible if the target word was a member of the category (e.g., "doe") and "no" if the target word was not a member of the category (e.g., "doubt"). Occasionally homophones (e.g., "dough") and pseudohomophones (e.g., "doh") were substituted for legitimate category members. VanOrden found that subjects incorrectly identified homophone substitutions as category members over 20 percent of the time as compared to only 3 percent of the time when the target word was not a category member. He also found the same pattern for pseudohomophones.

VanOrden has drawn two conclusions from the homophone substitution effects that he has found. First, phonology interferes with the processes involved in the category verification task, and therefore phonology plays some role in reading printed words, albeit in this case a largely counterproductive role. Second, and most importantly, the role of phonology in reading printed text occurs prior to lexical access. In his own words, "reading proceeds from spelling to sound to meaning." This means that access to word meaning is mediated by a phonological code. If a word is a homophone, then both concepts sharing that same phonological code will become activated; hence the confusion found in the homophone substitution effect. Furthermore, if the word is a pseudohomophone (e.g., any non-word that shares the phonology of a real word when recoded), then the concept associated with the phonology of the pseudohomophone will become activated and hence confusion will again arise.

It is pertinent to point out, however, that even though the homophone substitution effect occurs about 20 percent of the time, the effect does not occur almost 80 percent of the time. This means that an indirect phonological route is not the only route to the lexicon. If any model is supported by these results it is a model that allows both phonology and orthography to play a role in lexical access.

Pseudohomophone Effects

One of the first effects having implications for the role of phonology in lexical access was observed by Rubenstein, Lewis, and Rubenstein (1971). They presented letter strings to subjects and asked them to make a lexical decision concerning whether the letter string was a word or a non-word. In one experiment they included non-words of three types: unpronounceable and orthographically illegal non-words (e.g., "grunw"), pronounceable and orthographically illegal non-words (e.g., "crepf"), and pronounceable and orthographically legal non-words (e.g., "pronk"). The reaction times of subjects were fastest when the non-words were unpronounceable and orthographically illegal, and slowest when the non-words were pronounceable and orthographically legal. Rubenstein et al. concluded that pronounceability makes a non-word harder to reject in a lexical decision task because the availability of a phonological code forces a search of the lexicon whereas unpronounceable non-words can be rejected without a search of the lexicon.

To further test this assumption that pronounceable non-words prompt a search of the lexicon and require more time to reject, Rubenstein et al. designed a second experiment containing pronounceable and orthographically legal non-words (e.g., "pronk") and pronounceable and orthographically legal pseudohomophones (e.g., "brane"). As may be predicted, subjects required more time to reject pseudohomophones than non-pseudohomophones. This result was taken to support the view that, by virtue of their phonology, pseudohomophones activate a lexical entry for the homophonous word, and thus the subject must engage in a spelling check before deciding that the pseudohomophone is not a word. The slower rejection of pseudohomophones in a lexical decision task will be referred to as the pseudohomophone effect.

In a third experiment, homophones and non-homophones were used and the time required to accept them as words was measured. Rubenstein et al. found that it took longer for subjects to accept homophones as words than it took for them to accept non-homophones. To interpret this result, Rubenstein et al. suggested that subjects initially generate the phonological code for the word, then they search the lexicon seeking a phonological match. If the word is not a homophone, then the search will terminate when a lexical entry is found. If the word is a homophone, however, the search will occasionally terminate on the wrong homophone and a spelling check will be carried out before resuming the search. If the search of the lexicon is ordered by frequency, then incorrect matches will occur more often when the homophone is lower in frequency. This is in fact the pattern observed by Rubenstein et al: Lower frequency homophones took longer to accept than higher frequency homophones.

Several problems with the Rubenstein et al. data have arisen over the years. Clark (1973) re-analyzed the data treating items as well as subjects as random effects and found that the pseudohomophone effect and the homophone effect were no longer significant. The min F' statistic used by Clark, however, is a very stringent test of significance, and the Rubenstein et al. experiments were not specifically designed for the min F' statistic because relatively few stimuli were used. Clark acknowledged that the Rubenstein et al. data would probably have reached significance if more stimuli had been used but the purpose of his criticism was not to nullify the pseudohomophone effect, rather it was to point out that studies of this sort should be designed with use of the min F' statistic in mind and that more care should be taken when choosing stimuli.

A replication of the Rubenstein et al. study was conducted with these statistical considerations in mind (Coltheart, Davelaar, Jonasson, & Besner, 1977). They developed stimuli similar to the Rubenstein et al. study and found the same pattern of results for pseudohomophones (i.e., "brane took longer to reject than "brone"), but they did not find the same pattern for homophones (i.e., "hare" took no longer to accept than "harp") when the control words were matched for frequency and orthography.

Regularity Effects

In an effort to demonstrate the role of rule-based phonological recoding in word recognition, many studies have contrasted latencies for regular and irregular words in lexical decision tasks and naming tasks. Regular words are words that follow certain rules for pronunciation (e.g., "pink"), and irregular words are idiosyncratic in their pronunciation (e.g., "pint"). In early investigations of the effect of regularity on word recognition, longer latencies were found in both lexical decision tasks and naming tasks for irregular words when contrasted with regular words (Baron and Strawson, 1976; Stanovich and Bauer, 1978). This facilitation for regular words has become known as the regularity effect.

A subsequent series of investigations by Glushko (1979) replicated the regularity effect in a naming task, but several qualifications were required. Glushko distinguished between two types of regular words; regular consistent words that are always pronounced the same (e.g., "pink"), and regular inconsistent words that also follow the rules of pronunciation (e.g., "mint"), but for which there are cohort words that have irregular pronunciations (e.g., "pint"). Regular words of both types were more quickly pronounced than matched irregular words; however, Glushko found longer naming latencies for regular inconsistent words when contrasted with regular consistent words. Even though "mint" follows the rules for pronunciation just as "pink," the fact that other pronunciations of the "-int" ending are possible makes pronunciation of "mint" more difficult. Glushko took this as evidence against a rule-based phonological recoding process and for an orthographically based lexical analogy process in which words are pronounced by analogy to similarly spelled words in the lexicon.

As further evidence for the analogy model, Glushko compared latencies for regular consistent pseudowords (e.g., "bink") and regular inconsistent pseudowords (e.g., "bint") and found longer latencies for regular inconsistent pseudowords than regular consistent pseudowords. Glushko's results qualify the regularity effect to the extent that consistency and orthography also play a role in pronunciation.

The regularity effect has also been qualified by word frequency and subject variables. Seidenberg and colleagues (Seidenberg, Waters, Barnes, & Tanenhaus, 1984; Seidenberg, 1985; Seidenberg & McClelland, 1989) divided regular and irregular words into those that were high in frequency and those that were low in frequency. A regularity effect was found for low frequency words but no regularity effect was found for high frequency words. In addition, when subjects were blocked for reading speed, the regularity effect diminished for subjects having faster reading speeds.

Seidenberg interpreted these results as favoring a dual-route model in which the pronunciation of a word is generated by rules as well as by direct lexical retrieval. If the irregular word is high in frequency, then direct lexical retrieval is quick and the pronunciation is generated without recourse to GPC rules. However, if the irregular word is low in frequency, then direct lexical retrieval is slower and there is time for the GPC rules to generate the inappropriate and regularized pronunciation for the word. The generation of the regular and irregular pronunciations creates a conflict and slows the pronunciation of the irregular word. For regular words, whether they are high or low in frequency, the dual-route model will generate the same pronunciation for the word and no inhibition will be suffered as a result. Seidenberg (1985) points out that an interactive-activation model also makes these predictions.

Heterophonic Inhibition Effects

Another line of evidence that has been used to demonstrate the role of phonology in word recognition has been pioneered by Meyer, Schvaneveldt, and Ruddy (1974). In a lexical decision task, Meyer et al. presented word pairs that were either phonologically similar (e.g., "pitch-ditch" and "load-toad") or phonologically dissimilar (e.g., "lemon-demon" and "blow-plow"). Note that both pairs of words are orthographically similar. Meyer et al. reasoned that if word recognition is mediated by a phonological code, then latencies to phonologically dissimilar word pairs should be longer than latencies to phonologically similar pairs. This prediction is based upon the assumption that the mechanism by which visually presented words are recoded into phonological codes can be biased by recently recoded words. Thus, if you have just recoded the word "lemon," then the recoding mechanism will be biased toward recoding "demon" in the same way as "lemon," and recognition will fail as a result.

Meyer et al. found that response latencies for phonologically similar word pairs were faster than appropriately matched control pairs (e.g., "load-ditch" and "pitch-toad"). This effect will be referred to as "rhyme priming" and I will discuss this phenomenon shortly. But the primary finding in the Meyer et al. study was that response latencies for phonologically dissimilar word pairs were slower than appropriately matched control pairs (e.g., "lemon-plow" and "blow-demon"). This effect will be referred to as "heterophonic inhibition." Several studies have replicated and qualified this effect.

Shulman, Hornak, and Sanders (1978) replicated the heterophonic inhibition effect when the non-words were pronounceable pseudowords (e.g., "nize") but failed to replicate the effect when the non-words were unpronounceable letter strings (e.g., "znie"). They actually found that "lemon" facilitated recognition of "demon" when the non-words were unpronounceable. Shulman et al. considered this reversal of the heterophonic inhibition effect as evidence for the primary role of orthography in word recognition. When non-words are orthographically illegal, then words can be accepted solely on the basis of orthographic legality and subjects can skip the phonological recoding stage altogether. Note, however, that this conclusion only applies when the non-words are unpronounceable. Phonology continues to play a role, albeit a largely negative role, when the non-words are pronounceable.

In another study pertinent to the heterophonic inhibition effect, Hanson and Fowler (1987) demonstrated that phonology plays a role in word recognition even among the deaf. They replicated the heterophonic inhibition effects found by both Meyer et al. and Shulman et al. in subjects who were normal in hearing and in subjects who were congenitally deaf. This surprising result is evidence that the phonological code responsible for the heterophonic inhibition effect cannot be acoustic in nature but rather must be articulatory, as must certainly be the case among the congenitally deaf. This result raises the question of whether the locus of the heterophonic inhibition effect is prior to lexical access or after lexical access. It is even possible that the effect is due to subtle orthographic properties of these heterophonic word pairs. Despite the replicability of the effect, the heterophonic inhibition effect may not provide conclusive evidence that phonological recoding occurs during lexical access.

Rhyming Priming

A final line of evidence for phonological codes in lexical access that was alluded to in the previous section is rhyme priming. Facilitation from the word "pitch" to "ditch" was demonstrated by Meyer et al. in a lexical decision task and it could be argued that this priming effect was due to the phonological similarity between these words. However, in the case of "pitch" and "ditch," phonological similarity is confounded with orthographic similarity. In an effort to remove the confounding orthography, Hillinger (1980) presented the prime "pitch" auditorily in a cross-modal priming paradigm and found that the auditory prime facilitated the response to the visually presented target word "ditch" in a lexical decision task. Hillinger argued that because the prime stimulus was auditory, it could not have exerted its priming effect through its orthography.

In a second experiment using visually presented word pairs, Hillinger found facilitation for orthographically similar rhyme pairs (e.g., "late-mate") and facilitation for orthographically dissimilar rhyme pairs (e.g., "eight-mate") when compared to non-rhyme pairs (e.g., "veil-mate"). Again, rhyme priming was found when similar orthography was not confounded. These results would ordinarily constitute firm evidence for some role of phonology in word recognition; however, these results were not replicated in a later series of five studies by Martin and Jensen (1988).

In this section, I have presented several lines of evidence that purport to demonstrate the role of phonology in lexical access. Because most of these lines of evidence demonstrate effects on performance that involve either higher error rates or slower response latencies, the role of phonology in lexical access appears to be primarily negative.

The homophone substitution effect demonstrates that when people are asked to judge whether a sentence is correct they make many more errors when sentences contain homophone substitutions than when sentences contain orthographically similar but phonologically different substitutions. The pseudohomophone effect demonstrates that people take longer to reject non-words that can be pronounced like real words than they take to reject non-words that cannot be pronounced like real words. The regularity effect demonstrates that words having irregular spelling-to-sound correspondences take longer to accept as words than words having regular spelling-to-sound correspondences. And, the heterophonic inhibition effect demonstrates that words preceded by a prime having a different phonology take longer to accept as words than words preceded by a prime having a similar phonology.

The only line of evidence that purports to show a positive effect of phonology on lexical access is rhyme priming. Rhyme priming demonstrates that a word preceded by a rhyming word will be recognized faster than a word preceded by a non-rhyming word. If this result was replicable, then some positive evidence for phonology would be available. Unfortunately, rhyme priming has not been replicated under conditions where orthography is not confounded.

If any conclusions can be drawn from these lines of evidence, it is that phonology only serves to make performance slower and more prone to errors. But these lines of evidence have heretofore been presented under the assumption that the locus of these negative effects is during lexical access. It is entirely possible that these effects are post-lexical and that their locus is in short-term memory. As Seidenberg and McClelland (1989) argue, "Many studies have provided evidence that subjects use phonological information in reading, but ... this fact does not itself necessarily indicate that access of meaning was phonologically mediated." In the next section, I will discuss what it would mean for access of meaning to be phonologically mediated. I will begin by discussing several component processes involved in lexical priming, and I will finish by presenting several different types of priming effects; including multiple semantic priming, semantically mediated priming, and phonologically mediated priming.

Varieties of Lexical Priming

Priming effects have been used extensively to identify the component processes involved in word recognition. The most commonly observed effect is a semantic priming effect in which a word is recognized more quickly when it is preceded by a semantically related word than when it is preceded by a semantically unrelated word (Meyer & Schvaneveldt, 1971). Many types of semantic relationships have been found to produce priming effects; including antonyms (e.g., "light-dark"), synonyms (e.g., "bug-insect"), words within the same category (e.g., "tiger-lion"), and several other types of contiguous relationships (Warren, 1977).

These priming effects have been observed in both lexical decision tasks and naming tasks. The response latencies to target words in these tasks have been found to be anywhere from 10 to 50 milliseconds (ms) faster when the prime is a semantically related word than when the prime is an unrelated word. The amount of facilitation depends upon the duration of the prime stimulus and the interval of time between the offset of the prime and the onset of the target (otherwise known as the inter-stimulus interval, or ISI). The amount of time allotted for processing the prime is called the stimulus-onset asynchrony, or SOA, and it is computed by adding the ISI to the duration of the prime. In general, priming can occur at an SOA as short as 16 ms (Simpson & Burgess, 1985), and can be maintained for more than 40 seconds (Warren, 1972). The amount of facilitation typically peaks at SOAs anywhere between 150 and 350 ms, with facilitation attenuated at the extremes.

Of particular interest in this literature is the distinction between "automatic" and "controlled" processes (Shiffrin & Schneider, 1977). It appears that the priming effects observed at SOAs less than 300 ms are due to automatic processes, and that the priming effects observed at SOAs greater than 300 ms are due to controlled processes (Neely, 1977). Automatic processes are claimed to be obligatory to the extent that the subject has little control over their operation. The spreading activation model of the lexicon posits that during the initial stages of word recognition activation of nodes in the lexicon spreads automatically along every available link to other nodes. Controlled processes, on the other hand, are claimed to be driven by attentional mechanisms that select and maintain information in short-term memory. The priming effects observed several seconds after the presentation of the prime are probably due to the maintenance of the prime in short-term memory. If the subject has not been instructed to rehearse the prime, then facilitation will drop to zero after one second or so (Till, Mross, & Kintsch, 1988).

In an effort to empirically distinguish between automatic and controlled processes in word recognition, Neely (1977) employed a lexical decision task and told subjects to think of a building part (e.g., "door") every time they saw a prime representing a body part (e.g., "arm"). Under these conditions, Neely found facilitation at a 300 ms SOA for target words that were semantically related to the prime (e.g., "leg"), but found no facilitation for these targets at a 600 ms SOA, and even inhibition at a 2000 ms SOA. Although the subjects were told to think of a building part whenever they saw a body part, facilitation from "arm" to "leg" was observed at short SOAs. This facilitation at short SOAs was attributed to automatic spread of activation in the lexicon. The spread of activation was obligatory because despite being told to think of a building part, subjects could not help but activate semantically related lexical items. At longer SOAs there was no facilitation and even inhibition for the semantically related words. Neely attributed this inhibition of the semantically related items to controlled processes that actually suppressed the level of activation for these words.

More evidence for controlled processes came from trials where a body part (e.g., "arm") was followed by a building part (e..g., "door") as the subject was told to expect. Under these conditions, facilitation was observed at SOAs above 600 ms, but not at the 300 ms SOA. Neely attributed this result to controlled processes that require time to shift attention to lexical items for building parts that would not ordinarily become activated by automatic spread of activation from lexical items for body parts. Results such as these have been taken as convincing evidence that priming effects at short SOAs reflect automatic spread of activation in the lexicon and that priming effects at long SOAs reflect controlled processes involving a shift of attention from one class of semantically related words to another.

The distinction between automatic and controlled processes is crucial for the further distinction between pre-lexical phonological recoding and post-lexical activation of phonology. If the locus of the effect of phonology is pre-lexical, then phonology mediates lexical access and GPC rules automatically convert the printed word into a phonological code prior to lexical access. If the locus of the effect of phonology is post-lexical, then the activation of the phonological code for that word will depend upon a shift of attention to that code if the task requires the use of that code (i.e., if the task requires saying the word aloud). I will argue that it is possible to distinguish between pre- and post-lexical processes by manipulating the SOA in a priming study. If the effects of phonology are pre-lexical, then phonologically mediated priming effects should be observed at short SOAs. If, on the other hand, the effects of phonology are post-lexical, then phonologically mediated priming effects should be observed only at longer SOAs. I will now turn my attention to several additional types of priming effects that are relevant to the issue of phonologically mediated priming.

Multiple Semantic Priming

A prominent topic in the study of the lexicon is how words with more than one meaning (e.g., "mint') are coded and accessed. Are there separate lexical entries for ambiguous words or only a single entry? Are both meanings of an ambiguous word activated whenever it is seen or heard or is only the dominant meaning activated? If only one meaning of an ambiguous word fits the context of the sentence in which it occurs, how is this meaning selected? Is the other meaning suppressed or does its activation simply subside? These are just a few of the questions surrounding the issue of multiple semantic priming and, in this section, I will discuss several studies that have sought to discover how ambiguity is resolved in the lexicon.

In a cross-modal priming paradigm, Swinney (1979) presented auditory passages containing homonyms such as "bug" and asked subjects to make lexical decisions to a visually presented target word that was either unrelated to the prime (e.g., "sew") or related to each interpretation of the prime (e.g., "spy" and "ant"). The auditory passages were either neutral with regard to the interpretation of the ambiguous word, or biased toward one interpretation or the other. In addition, the target words were presented either immediately after the presentation of the ambiguous prime, or three syllables after the presentation of the prime.

Swinney found that when the target was presented immediately after the ambiguous prime, response latencies to the target were faster for words related to both interpretations of the prime than for words unrelated to the prime. This priming effect was observed whether the auditory passage was neutral or biased. These results suggest that both meanings of an ambiguous word become activated automatically, and that context plays no role in determining which meaning will be activated.

Swinney also found that when the target was presented three syllables after the ambiguous prime, response latencies to the target were faster only for the interpretation that was consistent with the auditory passage. Priming effects were not observed for the interpretation inconsistent with the context as well as the unrelated word. These results suggest that the meaning of the ambiguous word that is consistent with the context remains active (possibly because it has been retained in short-term memory for on-going sentence comprehension), while the meaning that is not consistent with the context loses activation (possibly because its activation has either subsided or been suppressed).

Swinney's paradigm has provided answers to several key questions concerning how ambiguous words are coded and accessed in the lexicon. An ambiguous word such as "mint" appears to have multiple representations in the lexicon. Both representations are automatically activated by the auditory (or visual) presentation of an ambiguous word regardless of the contextual bias. And, the contextual bias later exerts its effect by selecting the representation that is consistent with the context, and allowing the inconsistent representation to subside. The effects observed by Swinney in a cross-modal priming paradigm with sentential contexts have been replicated in both lexical decision tasks (Till, Mross, & Kintsch, 1988) and naming tasks (Tanenhaus, Leiman, & Seidenberg, 1979). Onifer and Swinney (1981) also replicated these findings when differences in frequency for each interpretation were controlled for.

Several additional studies have demonstrated multiple semantic priming effects in a single word priming paradigm. In a thorough investigation by Simpson and Burgess (1985), the time course of semantic activation for ambiguous words was determined by manipulating the SOA. Like Onifer and Swinney (1981), they were also interested in differences in the frequency of each interpretation: Targets were chosen that were either semantically related to the most frequent (or dominant) interpretation, or semantically related to the less frequent (or subordinate) interpretation.

Visually presented ambiguous primes were found to activate multiple meanings during a peak interval around 300 milliseconds after exposure. Activation for the less frequent (or subordinate) meaning rose to asymptote slowly, peaked briefly, and then declined to baseline, while activation for the more frequent (or dominant) meaning rose quickly to asymptote and remained steady for more than 750 milliseconds. Simpson and Burgess concluded that activation of multiple meanings involves a two-stage process: An initial automatic process that activates multiple meanings within 300 milliseconds and a controlled process that selectively maintains the activation level of only the dominant meaning (see also Neely, 1977).

In conclusion, words having dual meanings (homonyms) have been shown to activate both interpretations within a few hundred milliseconds in both sentential contexts and in single-word priming contexts. The demonstration of multiple semantic priming is significant for the discussion of phonologically mediated priming because it shows that more than one meaning of an ambiguous word will be activated when the SOA is relatively brief. However, if we are interested in phonologically mediated priming, then homonyms (e.g., "bug" and "mint") are not very helpful in determining which code, orthographic or phonological, is responsible for the observed multiple semantic priming effects because homonyms share the same sound and spelling. Homophones (e.g., "dough" and "doe") would be a better choice if we are interested in phonologically mediated priming because they sound the same but are spelled differently. If multiple semantic priming can be demonstrated with homophones, then we might be in a position to determine whether the priming effect was due to the phonological code or the orthographic code. I will return to the issue of phonologically mediated priming after I discuss semantically mediated priming.

Semantically Mediated Priming

A central assumption of the spreading-activation model of the lexicon is that when a lexical node is activated, the activation spreads along all available links to other associated nodes which, in turn, become activated and spread the activation further. Because there must be some constraints upon the spread of activation, Collins and Loftus (1975) posit a gradual reduction in the strength of activation as it spreads from node to node. One implication of this model is that priming effects may be predicted for semantically unrelated words (e.g., "lion" and "stripes") that share a related word in common (e.g., "tiger"). This type of priming will be referred to as semantically mediated priming.

Several experiments have sought to demonstrate semantically mediated priming. Balota and Lorch (1986) used both a lexical decision task and a naming task to determine if a prime such as "lion" would facilitate response latencies to a semantically mediated target such as "stripes." In this case, priming is mediated by the concept "tiger." Balota and Lorch found mediated priming effects for the naming task, but not for the lexical decision task. As predicted by the spreading-activation model, these effects were not as strong as direct semantic priming effects (e.g., "tiger" to "stripes"). Subsequent experiments by McNamara and Altarriba (1988) demonstrated semantically mediated priming effects in a lexical decision task using the same stimuli as Balota and Lorch. It is possible that Balota and Lorch did not find significant priming effect in the lexical decision task because the power of their study was not great enough to reveal what appears to be a small but reliable effect.

Phonologically Mediated Priming

The question that lies at the heart of the present investigation is whether phonology plays a prominent role in word recognition. I have presented several models of word recognition that provide a role for phonology in lexical access. I have also presented empirical evidence that purports to demonstrate the role of phonology in lexical access, along with several types of priming effects including multiple semantic priming and semantically mediated priming. It is now necessary to evaluate what it means for phonology to mediate lexical access in a priming paradigm.

I will begin with a discussion of cross-modal priming, where the prime is presented auditorily. In the case where the prime is presented auditorily, phonology clearly plays a role in lexical access. It is the phonological code for the prime that activates semantically related concepts in the lexicon, and therefore priming can be said to be mediated by a phonological code. Swinney's (1979) cross-modal priming effects using auditory primes embedded in a sentential context provide convincing evidence that multiple semantic priming effects occur when homonyms serve as primes. The auditory mode of prime presentation clearly implies that this multiple semantic priming effect is phonologically mediated. Based upon these results, it follows that homophones (e.g., "dough" and "doe") should also produce multiple semantic priming effects when they are made ambiguous through auditory presentation. In other words, we should find that auditory presentation of the prime /dō/ will activate multiple lexical representations including "bread" and "deer."

Multiple semantic priming in the case of auditorily presented homonyms and homophones is clearly mediated by a phonological code. But what can we predict for visually presented homophones? If lexical access in printed word recognition is mediated solely by an orthographic code, then only the lexical representations that match the orthographic code should be activated. We should therefore observe priming effects for the prime-target pairs "dough-bread" and "doe-deer." If lexical access in printed word recognition is mediated by a phonological code, however, then lexical representations that match the phonological code should be activated. We should then observe priming effects for phonologically mediated prime-target pairs such as "dough-deer" and "doe-bread." This is what I believe it means for phonology to mediate lexical access in a priming paradigm.

Any model of printed word recognition that provides a role for phonology in lexical access would predict phonologically mediated priming from "dough" to "deer." We are now in a position to evaluate two different ways that these models can account for phonologically mediated priming effects: pre-lexical phonological recoding and post-lexical activation of phonological codes. The direct phonological route model, the dual-route model, and the interactive-activation model each identify a pre-lexical phonological recoding processes as the means by which phonologically mediated priming exerts its effects. The modified direct orthographic route model also provides an account for phonologically mediated priming effects, but instead of pre-lexical processes, this model identifies post-lexical activation of phonological codes as the means by which priming can be phonologically mediated. I would like to take a moment to describe how these models differ with respect to their predictions regarding the speed and strength of phonologically mediated priming.

We have seen that priming effects are sensitive to the duration of the prime presentation by varying the SOA and observing the time course of semantic activation. We have also seen that priming effects are sensitive to the strength of activation by varying the degree to which prime-target pairs are associated. The time course of activation and the strength of activation are therefore two characteristics of lexical priming that can potentially discriminate between the several different models that provide accounts for phonologically mediated priming effects. I will now illustrate how this is possible for each model.

In the indirect phonological route model, the orthographic code for a printed word is automatically recoded into a phonological code prior to lexical access. Priming effects in this model are always mediated by a phonological code, therefore we should find that the time course and strength of activation for homophones should be identical to that found for homonyms by Simpson and Burgess (1985). Activation for the dominant meaning of the homophone should rapidly rise in strength and remain strong for over 750 ms. Activation for the subordinate meaning, however, should gradually rise in strength then subside. If the SOA is set at around 300 ms, the strength of activation for both the dominant and subordinate meanings should be about equal. These are the predictions made by any model of word recognition that involves only an indirect phonological route to the lexicon.

In the dual-route model, both the direct orthographic route and the indirect phonological route activate lexical items in parallel. Priming effects in this model may be mediated by an orthographic code, a phonological code, or both depending upon the rate at which these codes are generated. Because these rates are flexible, it is very difficult to make firm predictions concerning the strength and time course of priming effects for this model. If we can assume that the rates are the same, then we would be able to predict equally rapid activation for both meanings of a printed homophone, however, the strength of activation would be greater for the meaning that corresponds to the orthography of the printed homophone, all other things being equal. If the rate of activation for the orthographic code is faster than the rate of activation for the phonological code, then phonologically mediated priming effects should be less strong at shorter SOAs (Note, however, that phonological codes do not require more than 400 ms to activate because pronunciation latencies are in this range and therefore the two routes to the lexicon should not differ too greatly in speed of activation). These are some of the predictions that are made by the dual-route model, albeit somewhat unconstrained.

The interactive-activation makes predictions that are very similar to the dual-route model and it would be difficult to discriminate between the two models by measuring the the strength and time course of lexical priming. It is really only a small step from a parallel dual-route model of lexical access to a parallel interactive-activation model, therefore, the predictions made by one are going to be similar to the predictions made by the other. In addition, the fact that both models are very flexible makes them hard to evaluate. They seem to be able to account for almost any result retrospectively and this makes them somewhat difficult to refute. Many theorists find this feature attractive, but the lack of falsifiability makes these models difficult to evaluate scientifically.

A final model of word recognition that relies upon post-lexical processes to account for phonologically mediated priming effects is the modified direct orthographic route model. Priming effects in this model are mediated by an orthographic code during lexical access, but once a lexical item is activated, the activation spreads to all other items sharing the same phonological code. To the extent that this model makes the same predictions as the other pre-lexical models of lexical access, it becomes very difficult to determine whether phonologically mediated priming effects provide conclusive evidence for the role of phonology in lexical access. If any priming effect can potentially be attributed to post-lexical processes, then no conclusive evidence can be said to exist for pre-lexical processes. This difficulty underscores most of the problems that researchers have had over the years as they have struggled to provide clear evidence for the role of phonology in lexical access.

The difficulties encountered in attempts to verify and/or falsify the several models of word recognition attest to the longevity of these models and the abiding struggle to find points of divergence that will allow for empirical differentiation between the models. In the attempt to resolve whether phonology mediates lexical access, we are likely to discover a range of facts concerning the strength and time course of the activation of phonological codes in word recognition and reading. As facts accumulate, some models will lose prominence and other models more capable of accounting for the facts will supplant them, but phonologically mediated priming effects are independent of the models that do or do not predict them.

Logic of the Present Investigation

The present investigation is divided into four experiments. The first experiment is a replication of the multiple semantic priming effects found by Simpson and Burgess (1985). The stimuli consist of ten homonyms taken from studies by Onifer and Swinney (1981) and Till, Mross, and Kintsch (1988). The intent of Experiment 1 is to extend Swinney's (1979) multiple semantic priming effects to a visually based single word priming paradigm. Multiple semantic priming effects are predicted in both a lexical decision task and a naming task when visually presented homonyms serve as primes.

The second experiment is a direct test of phonologically mediated priming. The stimuli consist of ten homophone pairs (e.g., "dough-doe") that were chosen for their relative lack of orthographic similarity and the fact that both members of each homophone pair should be very familiar to college freshmen. If a visually presented homophone (e.g., "dough") is automatically converted into a phonological code prior to lexical access, as most models of word recognition assert, then priming would be predicted for words related to both members of the homophone pair (e.g., "bread" and "deer"). If phonology does not play any role in lexical priming, as the direct orthographic route model asserts, then priming would be predicted only for words related to the orthographically unambiguous homophone (i.e., priming from "dough" to "bread"). Experiment 2 is therefore a direct test of the role of phonology in lexical priming.

In Experiment 3, the primes and targets employed in Experiment 2 are reversed. In this case, the prime is an unambiguous word (e.g., "deer") and the target is one member of the homophone pair (i.e., either "doe" or "dough"). Unlike Experiment 2, Experiment 3 represents an indirect test of the role of phonology in lexical priming. If priming effects in the lexicon are mediated by a phonological code, then the visually presented prime "deer" would be predicted to prime recognition of the homophone "dough." This priming effect would be indirect because it would be mediated by the lexically activated phonological code /dō/. If mediated priming of this sort does not occur in the lexicon, then "deer" will not prime the recognition of "dough."

Experiment 4 employs a cross-modal priming paradigm with auditorily presented homophones as primes. Because homophones are ambiguous when presented auditorily, multiple semantic priming effects similar to those in Experiment 1 would be predicted. This experiment represents an attempt to verify that when a phonological code is used to access lexical entries, as must be the case with auditory word recognition, we would expect to find priming for words related to both meanings of the homophone.

Each of these experiments will be conducted with a 250 ms SOA. The duration of the prime will be 200 ms and the ISI will be 50 ms. This relatively brief SOA was chosen because I am primarily interested in whether phonologically mediated priming is due to automatic processes involved in lexical access and spreading activation. It is entirely possible that a longer SOA will reveal phonologically mediated priming effects, but such effects would probably be due to controlled processes involved in the selection and maintenance of phonological codes in short-term memory. These effects are not likely to be relevant to the question of the role of phonological codes in lexical access and spreading activation. I will now turn to a more detailed presentation of the methods and results of these four experiments.

EXPERIMENT 1

Preview

In the present study, the automatic activation of dual semantic interpretations for homonyms was investigated using a lexical decision task and a naming task. Because homonyms are spelled the same and sound the same, it is unclear whether the activation of multiple meanings is due to their orthographic properties or their phonological properties. Even though this experiment is not designed to address the issue of phonologically mediated priming, it is important to independently establish that an ambiguous word can automatically activate multiple semantic interpretations under controlled experimental conditions.

Lexical Decision Task

Method

Subjects

The subjects were 35 undergraduates enrolled in an Introductory Psychology course at the University of New Hampshire. Each student received one laboratory credit as part of a course requirement for participation.

Stimuli

Ten homonyms were adopted from previous studies by Onifer and Swinney (1980) and Till, Mross, and Kintsch (1988). The homonyms served as primes in the lexical decision task and each homonym (e.g., "mint") had two distinct interpretations. Twenty target words were then selected by choosing one semantically related word for each interpretation of each homonym (e.g., "candy" and "coin"). The homonyms and their respective target words were paired to create a "semantically related homonym" condition that consisted of prime-target pairs such as "mint-candy" and "mint-coin." The stimuli for this experiment appear in Appendix A.

Baseline conditions were created next by choosing a non-homonym that was semantically related to each of the target words (e.g., "cookie" and "nickel"). A non-homonym is any word that has only one interpretation. (Actually, most words have many shades of meaning and the distinction between "homonyms" and "non-homonyms" is a relative one. A glance at the non-homonyms used in this study will reveal some words with several shades of meaning, and even a few homophones.) The non-homonyms and the semantically related target words were paired to create a "semantically related baseline" condition that consisted of prime-target pairs such as "cookie-candy" and "nickel-coin." A "semantically unrelated baseline" condition was then created by pairing each non-homonym with an unrelated target word (e.g., "nickel-candy" and "cookie-coin"). And finally, a neutral baseline condition was created by simply using the word "blank" as a prime (e.g., "blank-candy").

The non-word target stimuli consisted of twenty orthographically legal and pronounceable non-words adapted from Rubenstein et al. (1971). The primes for the non-word targets were matched to the proportions of the primes for the word targets; there were five homonym primes, ten non-homonym primes, and five neutral primes. This was to ensure that subjects could not predict whether a trial was a "word" trial or a "non-word" trial on the basis of discrepant probabilities among the prime types. The non-word trials are presented in Appendix E.

Altogether there were twenty "non-word" targets and twenty "word" targets, making a total of forty targets. Four sets of forty prime-target pairs were created such that each target appeared only once. In addition, no primes appeared more than once. The twenty "word" trials were counterbalanced so that five trials consisted of homonym primes, five trials consisted of semantically related non-homonym primes, five trials consisted of semantically unrelated non-homonym primes, and five trials consisted of neutral primes. The twenty "non-word" trials were the same in each set. After these four sets of forty trials were created, each set was further divided into two subsets of twenty trials so that subjects would receive a break in the middle. Prior to presentation, each subset of twenty trials was randomized.

A set of twenty practice trials consisting of ten "word" trials and ten "non-word" trials was also created. The practice set also contained the same proportion of neutral trials as the experimental sets, but it did not contain any homonyms. The practice set is presented in Appendix G. In addition, there were three filler trials that appeared before every set, practice and experimental, so that early errors or difficulties would not adversely affect any experimental trials. These filler trials also appeared in all subsequent experiments and they were, in order; "winter-dog," "dream-loap(f)," and "blank-candle."

Two final considerations when choosing primes and targets for the experimental trials were word length and word frequency (Kucera and Francis, 1967). These variables were matched as evenly as possible for the homonym and non-homonym primes: For word length the means were 4.0 and 5.2 letters respectively and for word frequency the means were 24.0 and 25.2 words per million (wpm). The target words had a mean word length of 5.0 letters and a mean word frequency of 50.5 wpm. Note that only the primes defined the independent variable, and that the targets were the same for all conditions.

Apparatus

An Apple Macintosh computer was used to run this and all subsequent experiments. Routines for controlling stimulus presentation and reaction time collection were written by John Limber in Microsoft Basic. Millisecond timing routines were written by the Drexel Software Development Group in machine code (Westall, Perkey, and Chute, 1986; 1989). Because the clock used for timing events in the Macintosh is linked to the screen refresh rate (60 Hz), screen events such as prime and target duration are accurate to about 8 ms on any given trial.

Procedure

Each trial began with a fixation cross in the center of the screen. The duration of the fixation cross was 750 ms and it was followed by a blank screen which lasted 250 ms. The prime then appeared in the center of the screen for a duration of 200 ms. A 50 ms blank screen followed the prime before the target word appeared. This made the SOA 250 ms. The target then appeared in the center of the screen for 250 ms. The subject was instructed to respond to the target by pressing either a key labeled "Y" with the right index finger if the target was a word or a key labeled "N" with the left index finger if the target was a non-word. A millisecond timer was started upon the presentation of the target and was stopped upon the subject's response. If the subject's response was incorrect, an "ERROR" message appeared on the screen followed by three beeps. If the subject's response was correct, a number representing the reaction time in milliseconds appeared on the screen. Errors and reaction times were recorded in a data file containing all relevant stimulus and subject information. After a brief pause, the fixation cross appeared and the next trial commenced.

Subjects were run individually and each session lasted less than one half hour. The subjects were seated a comfortable distance from the screen and the brightness of the screen was adjusted to the subject's satisfaction. Peripheral screen flicker was reduced using a piece of cardboard with a two by three inch hole cut in the center. Subjects were told that the experiment was concerned with the speed and accuracy with which they could discriminate words from non-words. They were also told that three sets of 23 trials would be presented and that the first three trials would be the same in each set. The practice set was then presented, followed by the two experimental sets with brief breaks in between while each new set was randomized. When the last set was completed, the subjects were shown their data and a debriefing statement was provided.

Data Analysis

The data from this and all subsequent experiments were analyzed in the following manner. Reaction times greater than 2000 ms and less than 100 ms were excluded from the analysis.[1] Error rates were computed for each of the prime-target conditions. Subjects were omitted from further analyses if their error rates were greater than 25%. Any subject omitted by this rule was replaced with another whenever possible. Subject effects (F_1) were analyzed by computing a mean reaction time for each subject across each condition, treating items as a fixed effect. Item effects (F_2) were also analyzed by computing a mean reaction time for each item across each condition, treating subjects as a fixed effect.

Significance tests were run for item effects and subject effects using a repeated measures analysis of variance model. Using the semantically unrelated prime condition as the baseline, separate F-tests were run comparing each experimental condition to the baseline. The effect size (r) was then computed for each comparison (Rosenthal, 1984).[2] A positive effect size reflected priming effects involving facilitation and a negative effect size reflected

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[1] The data were analyzed using other less conservative data trimming procedures without any substantive changes in the pattern of results. In addition, inverse and logarithmic transformations were employed, again without any substantive changes in the pattern of results.

inhibition. Finally, the min F' statistic for effects across subjects (F_1) and items (F_2) was calculated (Clark, 1973).[3] The alpha level for all significance tests was set at $p < .05$.

Results and Discussion

The baseline conditions in this experiment provide anchor points against which the priming effects of homonyms can be measured. If multiple semantic priming occurs within 250 ms, then the priming effect for homonym primes should be equivalent to the priming effect for the semantically related non-homonym primes. The semantically unrelated primes and the neutral primes represent baselines where, by definition, no priming exists. There should be no difference between the semantically unrelated baseline and the neutral baseline. Both are used because several investigators have claimed that neutral primes such as "blank" constitute the appropriate baseline (deGroot, Thomassen, & Hudson, 1982; Lorch, Balota & Stamm, 1986).

Error Rates

The percentage of errors was highest in the semantically unrelated baseline condition, 11.9%, and lowest in the semantically related baseline condition, 4.7%. The neutral baseline condition and the homonym condition produced error rates of 5.5% and 8.7% respectively.

Subject Effects

The semantically unrelated baseline condition yielded a mean reaction time of 616 ms (SD = 104 ms), and the neutral baseline condition yielded a

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[2] The formula for the r statistic is given by Rosenthal (1984):

$$r^2 = F(1, x) / [F(1, x) + df_{error}]$$

[3] The formula for the min F' statistic is given by Clark (1973):

$$\min F'(i,j) = F_1F_2 / (F_1 + F_2)$$

mean reaction time of 625 ms (SD = 114 ms). The difference between these baselines was not significant; $F(1,34) = 0.37$, and the effect size (r) was -.104.

The semantically related baseline condition yielded a mean reaction time of 580 ms (SD = 101 ms). The difference between this baseline and the unrelated baseline was significant; $F(1,34) = 10.36$, $r = +.483$, indicating moderately strong facilitation for semantically related primes. The homonym condition yielded a mean reaction time of 572 ms (SD = 90 ms). The difference between this experimental condition and the unrelated baseline was also significant; $F(1,34) = 14.30$, $r = +.544$, indicating moderately strong facilitation for homonym primes. In addition, the difference between the homonym condition and the semantically related condition was not significant; $F(1,34) = 0.47$. These last three results indicate that homonyms produce as much semantic priming as non-homonyms. Table 1 presents these results for the subject effects.

Item Effects

The item effects were found to be similar to the subject effects and they are presented in Table 1 as well. The mean reaction times for the unrelated and neutral baseline conditions were 622 ms (SD = 103 ms) and 618 ms (SD = 79 ms) respectively. This difference was not significant; $F(1,19) = 0.02$, $r = +.032$.

The mean reaction time for the related baseline condition was 577 ms (SD = 58 ms). The difference between the related and unrelated baseline conditions was significant; $F(1,19) = 7.51$, $r = +.532$. The mean reaction time for the homonym condition was 576 ms (SD = 64 ms). The difference between the homonym condition and the unrelated baseline condition was also significant; $F(1,19) = 6.85$, $r = +.515$. And finally, the difference between the homonyms and the semantically related baseline was not significant; $F(1,19) = 0.00$. Again,

Table 1.

Lexical Decision Error Rates, Subject Effects, Item Effects, and min F' Statistics across Conditions in Experiment 1.

		Subject Effects				Item Effects				
Prime-Target	ER(%)	RT	SD	F(1,34)	r	RT	SD	F(1,19)	r	min F'
bug-ant	8.7	572	90	14.30*	+.544	576	64	6.85*	+.515	4.65*
insect-ant	4.7	580	101	10.36*	+.483	577	58	7.51*	+.532	4.35*
secret-ant	11.9	616	104	—	—	622	103	—	—	—
blank-ant	5.5	625	114	0.37	-.104	618	79	0.02	+.032	0.02

* $p < .05$

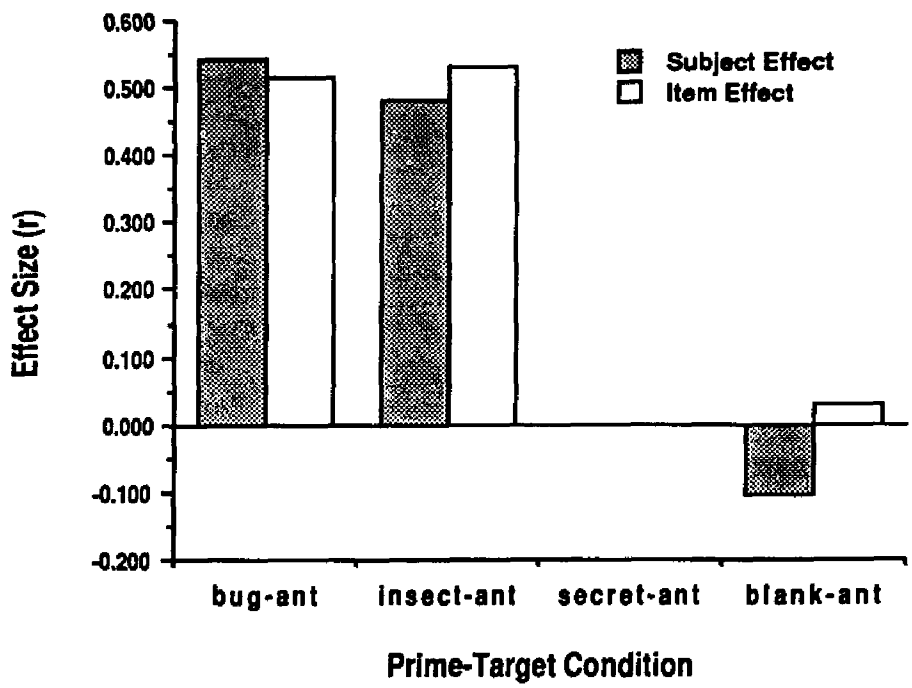

Figure 6. Effect size (r) plotted for each prime-target condition: Experiment 1, lexical decision task.

these results indicate that homonyms produce as much semantic priming as non-homonyms.

The min F' Statistic

The min F' statistic is a measure of how well the effects of a manipulation can be predicted to generalize to new samples of subjects and items (Clark, 1973). The min F' statistic was calculated only if both F_1 and F_2 were significant. Comparing the related baseline with the unrelated baseline, the min F' statistic was significant; $F(1,44) = 4.35$. In addition, the min F' for the difference between the homonym condition and the unrelated baseline was significant; $F(1,37) = 4.65$. Considering the fact that the min F' statistic is an extremely stringent test, these results provide strong evidence for multiple semantic priming when homonyms are used as primes in a lexical decision task. Figure 6 presents a graph plotting the effect sizes for each prime-target condition against the unrelated baseline condition.

Naming Task

Method

Subjects

The subjects were 88 students enrolled in an Introductory Psychology course at the University of New Hampshire. Each student received one laboratory credit toward a course requirement for participation.

Stimuli

The stimuli were the same as in the lexical decision task, except for the fact that the naming task does not require non-words. The non-word targets were therefore replaced with filler words. These exchanges are noted in Appendix E. The primes as well as the practice trials and filler trials also remained the same as those in the lexical decision task.

Apparatus

The routines that controlled the stimulus presentation for this experiment were written in HyperTalk and the scripts appear in Appendix H. Upon presentation of each target word, an inaudible tone was sent to a Technics tape deck and recorded. The subject's responses for each trial were also recorded on the tape using a microphone. The tapes were later digitized using a MacRecorder™ and analyzed using SoundEdit.™ The naming latencies were obtained by measuring the interval between the onset of the tone and the onset of the subject's voice on the tape. This apparatus was used for all subsequent naming task experiments.

Procedure

Each trial began with a fixation cross lasting 750 ms followed by a blank screen for 250 ms. The prime was then presented for 200 ms followed by a 50 ms ISI. As in the lexical decision task, the SOA was 250 ms. The target appeared next and lasted 250 ms. Subjects were instructed to respond to the target by pronouncing the word aloud into the microphone as quickly and yet as clearly as they could. Errors and reaction times were later transcribed from the tapes and recorded in a data file containing all relevant stimulus and subject information. After a 2 second pause, the fixation cross appeared and the next trial commenced.

Subjects were run individually and each session lasted less than one half hour. They were told that the experiment was concerned with the speed and accuracy with which they could pronounce words. They were also told that three sets of 23 trials would be presented and that the first three trials would be the same in each set. The practice set was then presented, followed by the two experimental sets with brief breaks in between. When the last set was completed, the subjects were shown their data and a debriefing statement was provided.

Results and Discussion

Subject Effects

The semantically unrelated baseline condition yielded a mean reaction time of 433 ms (*SD* = 75 ms), and the neutral baseline condition yielded a mean reaction time of 437 ms (*SD* = 78 ms). The difference between these baselines was not significant; $F(1,87) = 0.54$, and the effect size (r) was -.079.

The semantically related baseline condition yielded a mean reaction time of 427 ms (*SD* = 72 ms). The difference between this baseline and the unrelated baseline was not significant; $F(1,87) = 1.55$, $r = +.132$. The homonym condition yielded a mean reaction time of 431 ms (*SD* = 70 ms). The difference between this experimental condition and the unrelated baseline was also not significant; $F(1,87) = 0.25$, $r = +.054$. In addition, the difference between the homonym condition and the semantically related condition was not significant; $F(1,87) = 0.58$. These results indicate that semantic priming effects for both homonyms and non-homonyms are extremely weak in the naming task. Table 2 presents these results for the subject effects.

Item Effects

The item effects were also found to be weak for both homonyms and non-homonyms. They are presented in Table 2 as well. The mean reaction times for the unrelated and neutral baseline conditions were 432 ms (*SD* = 35 ms) and 436 ms (*SD* = 42 ms) respectively. This difference was not significant; $F(1,19) = 0.17$, $r = -.094$.

The mean reaction time for the related baseline condition was 425 ms (*SD* = 44 ms). The difference between the related and unrelated baseline conditions was not significant; $F(1,19) = 1.25$, $r = +.248$. The

Table 2.

Naming Task Subject Effects, Item Effects, and min F' Statistics across Conditions in Experiment 1.

	Subject Effects				Item Effects				
Prime-Target	RT	SD	F(1,87)	r	RT	SD	F(1,19)	r	min F'
bug-ant	431	70	0.25	+.054	430	37	0.09	+.069	0.07
insect-ant	427	72	1.55	+.132	425	44	1.25	+.248	0.69
secret-ant	433	75	---	---	432	35	---	---	---
blank-ant	437	78	0.54	-.079	436	42	0.17	-.094	0.13

* p < .05

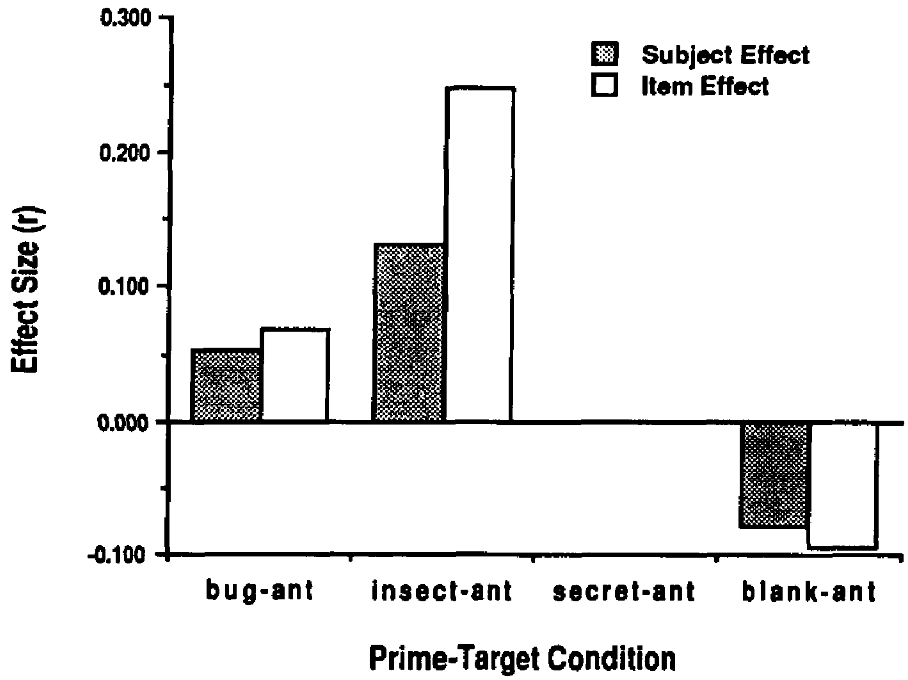

Figure 7. Effect size (r) plotted for each prime-target condition: Experiment 1, naming task.

mean reaction time for the homonym condition was 430 ms (SD = 37 ms). The difference between the homonym condition and the unrelated baseline condition was also not significant; $F(1,19) = 0.09$, $r = +.069$. And finally, the difference between the homonyms and the semantically related baseline was not significant; $F(1,19) = 0.37$. Again, these results indicate a failure to demonstrate semantic priming effects for homonyms and non-homonyms in a naming task.

The min F' Statistic

Because none of the individual F-tests proved significant, min F' statistics were not computed. Figure 7 presents a graph plotting the effect sizes for each prime-target condition against the unrelated baseline condition. Note that all effects sizes appear to be in the right direction, but they are extremely weak.

The failure to demonstrate even semantic priming in this naming task calls into question the usefulness of this data for understanding multiple semantic priming. These results are atypical because many studies (including the remaining studies in the present investigation) have demonstrated semantic priming with a naming task. Although, it is theoretically improper to discard data just because they do not support cherished assumptions, it is necessary to declare these results irrelevant to the issue of multiple semantic priming due to the absence of a semantic priming effect.

EXPERIMENT 2

Preview

Experiment 2 represents an attempt to demonstrate phonologically mediated priming effects in a lexical decision task and in a naming task. The SOA in these tasks will be 250 ms to assure that if phonologically mediated priming is observed it is driven by automatic processes and not controlled processes. The homophones used in this experiment were selected from Hobbs' Homophones and Homographs: An American Dictionary (1987). Because homophones share the same phonology, but not the same orthography, they provide ideal stimuli for separating the effects of phonology from the effects of orthography in word recognition.

Lexical Decision Task

Method

Subjects

The subjects were 61 undergraduates enrolled in an Introductory Psychology course at the University of New Hampshire. Subjects received one laboratory credit toward a course requirement for their participation.

Stimuli

Ten homophone pairs were selected from a corpus of over 1800 homophone pairs available in the English language. They were selected with two criteria in mind: Both members of each homophone pair had to be familiar to college freshmen, and their spellings had to be as dissimilar as possible to control for orthographic variables. The homophones served as primes for a set of twenty target words which were semantically related. By pairing each homophone with its corresponding target word (e.g., "dough-bread" and "doe-deer"), a "semantically related homophone" condition was created. Also, by pairing each homophone with the target word associated with its counterpart (e.g., "dough-deer" and "doe-bread"), a "phonologically mediated homophone" condition was created. Note that these two conditions were created with the same primes and targets so that any differences which emerge as a result must be due primarily to the differences between the homophones (i.e., differences in orthography and meaning). The stimuli for this experiment appear in Appendix B.

The baseline conditions were created next by selecting twenty words that were semantically related to each of the targets (e.g., "fawn" and "yeast"). A "semantically related" baseline was created by pairing the related words with the corresponding targets (e.g., "fawn-deer" and "yeast-bread"). A "semantically unrelated" baseline was then created by reversing the related prime-target pairs (e.g., "fawn-bread" and "yeast-deer"). The word "blank" was used to create a "neutral" condition to round out the baseline conditions.

The homophone primes and the baseline primes were matched as closely as possible for both word length and word frequency. The respective means for word length were 4.5 and 4.6 letters, and the respective means for word frequency were 26.6 and 23.8 wpm. For the target words, the mean word length was 5.1 letters and the mean word frequency was 35.7 wpm.

The non-word targets used in this experiment were the same as those used in the lexical decision task of Experiment 1. The only difference was that the primes for the non-words consisted of homophones rather than homonyms. The non-words along with their primes appear in Appendix F.

As in Experiment 1, there were forty targets altogether; twenty "word" targets and twenty "non-word" targets. Five sets of forty prime-target pairs were created such that no primes or targets appeared more than once. The primes for the twenty "word" targets in each set were systematically counterbalanced so that there were four primes from each of the five prime types. The primes for the twenty "non-word" trials were the same in each set. Each set of forty trials was then divided into two subsets of twenty trials and each subset was randomized prior to presentation. Subjects were randomly assigned to each set and the order of the subsets was counterbalanced across subjects. All filler trials and practice trials were the same as in the lexical decision task of Experiment 1.

Procedure

The Apple Macintosh computer and the routines for controlling the presentation of stimuli were identical to those used for the lexical decision task in Experiment 1.

The procedure was also identical to that used previously. The SOA was 250 ms, and the subjects were run individually. At the conclusion of the experiment, the subjects were shown their data and debriefed.

Results and Discussion

Error Rates

The highest error rates were found in the semantically unrelated baseline condition and the phonologically mediated homophone condition (9.9% and 8.2% respectively), and the lowest error rates were found in the semantically related baseline condition and the semantically related homophone condition (5.4% and 6.2% respectively). The error rate for the neutral baseline condition was also 6.2%.

Subject Effects

The semantically unrelated baseline condition yielded a mean reaction time of 570 ms (SD = 81 ms), and the neutral baseline condition yielded a mean reaction time of 590 ms (SD = 90 ms). The difference between these baselines was not significant; $F(1,60) = 2.53$, and the effect size (r) was -.201.

Table 3.

Lexical Decision Error Rates, Subject Effects, Item Effects, and min F' Statistics across Conditions in Experiment 2.

		Subject Effects				Item Effects				
Prime-Target	ER(%)	RT	SD	F(1,60)	r	RT	SD	F(1,19)	r	min F'
doe-deer	6.2	549	70	4.89*	+.275	552	43	2.35	+.332	1.59
dough-deer	8.2	575	80	0.29	-.069	578	51	0.09	-.069	0.07
fawn-deer	5.4	547	75	5.92*	+.300	548	41	2.83	+.360	1.92
yeast-deer	9.9	570	81	—	—	573	58	—	—	—
blank-deer	6.2	590	90	2.53	-.201	593	51	3.13	-.376	1.40

* $p < .05$

The semantically related baseline condition yielded a mean reaction time of 547 ms (SD = 75 ms). The difference between this baseline and the unrelated baseline was significant; $F(1,60) = 5.92$, $r = +.300$, indicating moderately strong facilitation for semantically related primes. The semantically related homophone condition yielded a mean reaction time of 549 ms (SD = 70 ms). The difference between this homophone condition and the unrelated baseline was also significant; $F(1,60) = 4.89$, $r = +.275$, indicating moderately strong facilitation for semantically related homophone primes. Finally, the phonologically mediated homophone condition yielded a mean reaction time of 575 ms (SD = 80 ms). The difference between this homophone condition and the unrelated baseline, however, was not significant; $F(1,60) = 0.29$, $r = -.069$. Taken together, these last three results indicate that semantically related homophones produce as much semantic priming as semantically related non-homophones, but that phonologically mediated homophones do not produce any more priming than unrelated non-homophones; results that argue strongly against phonologically mediated priming. The subject effects for this lexical decision task appear in Table 3.

Item Effects

The item effects showed the same pattern of results as the subject effects, and they also appear in Table 3. Although the effect sizes for the items were actually greater than the effect sizes for the subjects, they were not significant due to the fact that there were more subjects than items by a ratio of three to one.

The mean reaction times for the unrelated and neutral baseline conditions were 573 ms (SD = 58 ms) and 593 ms (SD = 51 ms) respectively. This difference, however, was not significant; $F(1,19) = 3.13$, $r = -.376$, indicating moderately strong inhibition for the neutral primes. This was actually the strongest inhibition observed for the neutral baseline in all of the experiments. Overall, the neutral baseline produced inhibition, but it was generally very weak (i.e., effect sizes for the neutral baseline averaged -.040 with a standard deviation of .137).

The mean reaction time for the semantically related baseline condition was 548 ms (SD = 41 ms), and the difference between this baseline and the unrelated baseline was non-significant; $F(1,19) = 2.83$, but the effect size (r) was +.360, indicating moderately strong facilitation for the semantically related baseline primes. The mean reaction time for the semantically related homophone condition was 552 ms (SD = 43 ms), and the difference between this homophone condition and the unrelated baseline was also non-significant; $F(1,19) = 2.35$, and the effect size (r) was +.332, again indicating moderately strong facilitation for the semantically related homonym primes. And finally, the mean reaction time for the phonologically mediated homophone condition was 578 ms (SD = 51 ms). The difference between this homophone condition and the unrelated baseline was also not significant; $F(1,19) = 0.09$, $r = -.069$. These last three results, taken together, indicate moderately strong priming effects for semantically related homophones and non-homophones, but extremely weak priming effects for phonologically mediated homophones; a result that again speaks unfavorably for phonologically mediated priming.

The min F' Statistic

The min F' statistics for each of the comparisons are presented in Table 3, but none are significant. The reason for this lies in the fact that the min F' statistic can never be significant if either F_1 or F_2 is non-significant. Because the item effects lack the power of the subject effects in this and all of the other experiments to be reported, the min F' statistic is probably not an appropriate test. Because it is such a stringent test, the power of both F_1 and F_2

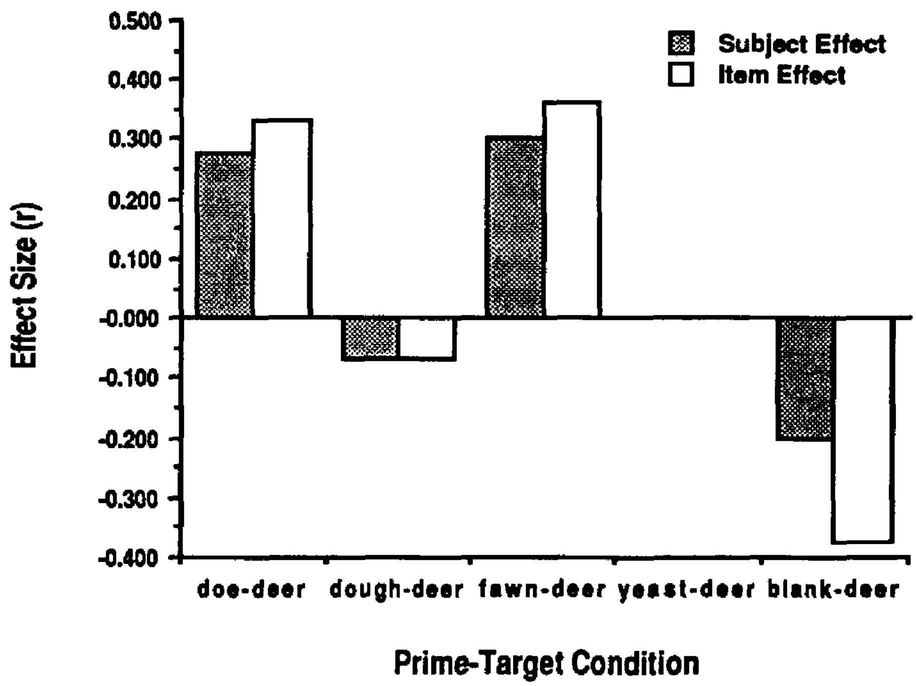

Figure 8. Effect size (r) plotted for each prime-target condition: Experiment 2, lexical decision task.

should be equal if the min F' is to be meaningful. This calls into question the use of the min F' statistic in these experiments where the power of F_1 is not equal to the power of F_2.

The min F' statistics for each comparison will continue to be computed hereafter, however, more emphasis will be placed upon the effect sizes. The effect size is not usually influenced by lack of power (Rosenthal, 1984); and furthermore, the effect size provides a more realistic measure of facilitation and inhibition in a priming paradigm because it provides an estimate of how much of an effect a prime exerts upon the response to a target; rather than merely indicating that the effect is significant for some arbitrary alpha level. The effect sizes for the subject and item effects in this study are presented in Figure 8. Facilitation and inhibition are clearly represented by these effect sizes for each of the prime-target conditions in the lexical decision task.

Naming Task

Method

Subjects

The subjects were 60 undergraduates enrolled in an Introductory Psychology course at the University of New Hampshire. The students each received one laboratory credit toward a course requirement for their participation.

Stimuli

The naming task does not require non-words, therefore, the non-word targets were replaced with filler words. Otherwise, the stimuli were identical to those used in the above lexical decision task.

Apparatus

The Apple Macintosh computer and the routines for controlling the presentation of stimuli and the collection of reaction time data were the same as those used for naming task in Experiment 1.

Procedure

The procedure was also identical to that used in Experiment 1. The SOA was 250 ms, and the subjects were run individually. All responses were recorded onto tape and later digitized for analysis At the conclusion of the experiment, the subjects were shown their data and debriefed.

Results and Discussion

Subject Effects

The semantically unrelated baseline condition yielded a mean reaction time of 432 ms (SD = 68 ms), and the neutral baseline condition yielded a mean reaction time of 432 ms (SD = 70 ms). The difference between these baselines was not significant; $F(1,59) = 0.00$, and the effect size (r) was .000.

The semantically related baseline condition yielded a mean reaction time of 412 ms (SD = 65 ms). The difference between this baseline and the unrelated baseline was significant; $F(1,59) = 18.03$, $r = +.484$, indicating strong facilitation for semantically related primes. The semantically related homophone condition yielded a mean reaction time of 417 ms (SD = 66 ms). The difference between this homophone condition and the unrelated baseline was also significant; $F(1,59) = 11.03$, $r = +.397$, indicating strong facilitation for semantically related homophone primes. Finally, the phonologically mediated homophone condition yielded a mean reaction time of 430 ms (SD = 74 ms). The difference between this homophone condition and the unrelated baseline, however, was not significant; $F(1,59) = 0.14$, $r = +.049$, indicating extremely weak facilitation for phonologically mediated homophone primes. Taken together, these last three results indicate that semantically related homophones produce as much semantic priming as semantically related non-homophones, but that phonologically mediated homophones do not produce any more priming than unrelated non-homophones; results that again argue strongly against phonologically mediated priming. The subject effects for this naming task appear in Table 4.

Item Effects

The item effects showed the same pattern of results as the subject effects, and they also appear in Table 4. The mean reaction times for the unrelated and neutral baseline conditions were 432 ms (SD = 35 ms) and 432 ms (SD = 37 ms) respectively. This difference was not significant; $F(1,19) = 0.00$, $r = .000$.

The mean reaction time for the semantically related baseline condition was 412 ms (SD = 30 ms), and the difference between this baseline and the unrelated baseline was significant; $F(1,19) = 9.67$, and the effect size (r) was +.581, indicating strong facilitation for the semantically related baseline primes. The mean reaction time for the semantically related homophone condition was 418 ms (SD = 30 ms), but the difference between this homophone condition and the unrelated baseline was not significant; $F(1,19) = 3.27$, and the effect size (r) was +.383, again indicating moderately strong facilitation for the semantically related homophone primes. And finally, the mean reaction time for the phonologically mediated homophone condition was 431 ms (SD = 40 ms). The difference between this homophone condition and the unrelated baseline was also not significant; $F(1,19) = 0.05$, $r = +.051$. These last three results, taken together, indicate strong priming effects for semantically related homophones and non-homophones, but extremely weak priming effects for phonologically mediated homophones; a result that once again does not provide support for phonologically mediated priming.

Table 4.

Naming Task Subject Effects, Item Effects, and min F' Statistics across Conditions in Experiment 2.

	Subject Effects				Item Effects				
Prime-Target	RT	SD	F(1,59)	r	RT	SD	F(1,19)	r	min F'
doe-deer	417	66	11.03*	+.397	418	30	3.27	+.383	2.52
dough-deer	430	74	0.14	+.049	431	40	0.05	+.051	0.04
fawn-deer	412	65	18.03*	+.484	412	30	9.67*	+.581	6.29*
yeast-deer	432	68	---	—	432	35	—	—	---
blank-deer	432	70	0.00	+.000	432	37	0.00	+.000	0.00

* $p < .05$

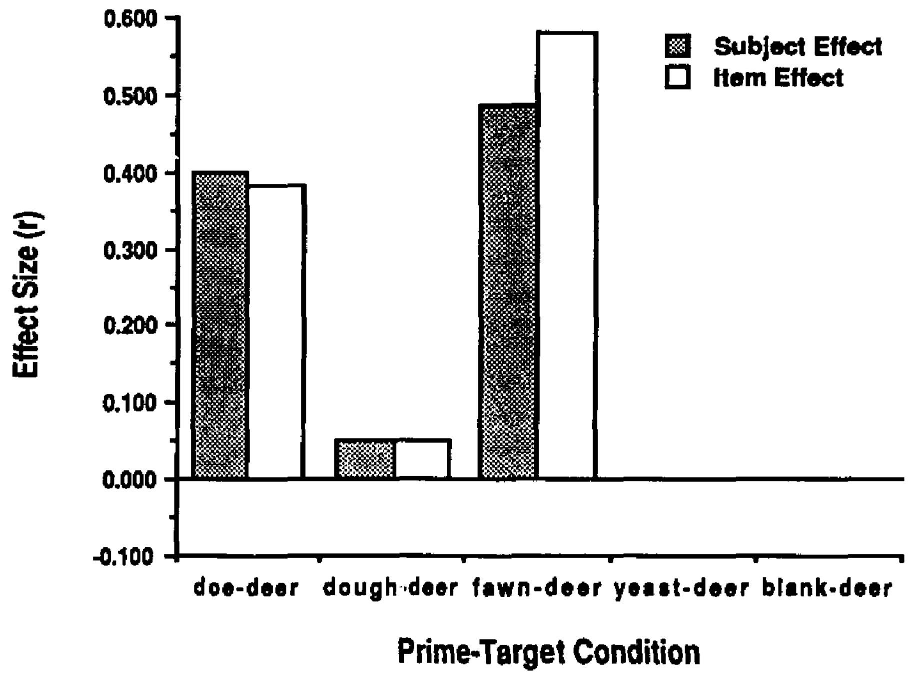

Figure 9. Effect size (r) plotted for each prime-target condition: Experiment 2, naming task.

The min F' Statistic

The min F' statistics for all comparisons appear in Table 4. The only effect that yielded significance was for the semantically related baseline condition when compared to the unrelated baseline; $F(1,41) = 6.29$. Figure 9 presents the effect sizes plotted for subject effects and item effects across prime-target conditions. Facilitation and inhibition are once again clearly represented by the effect sizes for each of the prime-target conditions in the naming task.

EXPERIMENT 3

Preview

The homophones used in this experiment were the same as those used in Experiment 2, but the primes and the targets were reversed. This procedure created conditions in which the homophones served as targets instead of primes (i.e., the word "deer" became the prime and the homophone "dough" became the target). Because the homophones were the targets in this experiment, strictly speaking, this experiment does not address the issue of phonologically mediated priming. The motivation for this reversal was provided by evidence for the homophone substitution effect. VanOrden (1988) presented categories such as "a type of deer" followed by a target word that was either a category member such as "doe" or a non-member homophone such as "dough." In these experiments, VanOrden found higher error rates for homophone substitutions and concluded that recognition of the target word was mediated by a phonological code. By using homophones as targets, the present experiment was designed to simulate the conditions of VanOrden's experiments.

Lexical Decision Task

Method

Subjects

The subjects were 61 students enrolled in an Introductory Psychology course at the University of New Hampshire. The students each received one laboratory credit toward a course requirement for their participation.

Stimuli

The stimuli were the same as those used in Experiment 2; only the primes and targets were reversed. By pairing each homophone target with a semantically related prime (e.g., "bread-dough" and "deer-doe"), a "semantically related homophone" condition was created. In addition, by pairing each homophone target with a prime associated with its homophone counterpart (e.g., "deer-dough" and "bread-doe"), a "phonologically mediated homophone" condition was created. The stimuli appear in Appendix C.

A "semantically related" baseline was created next by pairing the semantically related baseline primes with the corresponding homophone targets (e.g., "fawn-doe" and "yeast-dough"). A "semantically unrelated" baseline was also created by randomly assigning unrelated baseline primes with each homophone target (e.g., "shield-dough" and "brush-doe"). The word "blank" was used to create a "neutral" condition to round out the baseline conditions.

The non-word targets used in this experiment were the same as those used in the lexical decision task of Experiment 2. The remaining procedures for randomizing and counterbalancing the sets of stimuli were also identical to those in Experiment 2.

Procedure

The Apple Macintosh computer and the routines for controlling the presentation of stimuli were identical to those used for previous lexical decision tasks. The SOA was set at 250 ms, and the subjects were run individually. At the conclusion of the experiment, the subjects were shown their data and debriefed.

Results and Discussion

Error Rates

The error rates found in the neutral baseline condition, the semantically unrelated baseline condition and the phonologically mediated homophone condition were 17.8%,13.6%, and 12.5% respectively. The error rates found in the semantically related baseline condition and the semantically related homophone condition were 10.3% and 8.6% respectively.

Subject Effects

The semantically unrelated baseline condition yielded a mean reaction time of 602 ms (SD = 86 ms), and the neutral baseline condition yielded a mean reaction time of 608 ms (SD = 102 ms). The difference between these baselines was not significant; $F(1,60) = 0.17$, $r = -.053$.

The semantically related baseline condition yielded a mean reaction time of 588 ms (SD = 94 ms). The difference between this baseline and the unrelated baseline was not significant; $F(1,60) = 1.80$, $r = +.171$. The semantically related homophone condition yielded a mean reaction time of 566 ms (SD = 77 ms). The difference between this homophone condition and the unrelated baseline was significant; $F(1,60) = 8.51$, $r = +.352$. Finally, the phonologically mediated homophone condition yielded a mean reaction time of 606 ms (SD = 102 ms). The difference between this homophone condition and the unrelated baseline, however, was not significant; $F(1,60) = 0.08$, $r = -.036$. Taken together, these last three results indicate that the "semantically related homophone" condition produced more semantic priming than the "semantically related baseline" condition, but that the "phonologically mediated homophone" condition did not produce any more priming than the unrelated baseline. It is not clear why the semantically related baseline showed such weak priming, but overall, these results do not provide any support for phonologically mediated priming. The subject effects for this lexical decision task appear in Table 5.

Item Effects

The item effects showed the same pattern of results as the subject effects, and they also appear in Table 5. The mean reaction times for the unrelated and

Table 5.

Lexical Decision Error Rates, Subject Effects, Item Effects, and min F' Statistics across Conditions in Experiment 3.

		Subject Effects				Item Effects				
Prime-Target	ER(%)	RT	SD	F(1,60)	r	RT	SD	F(1,19)	r	min F'
deer-doe	8.6	566	77	8.51*	+.352	572	72	10.68*	+.600	4.74*
bread-doe	12.5	606	102	0.08	-.036	622	106	0.25	-.114	0.06
fawn-doe	10.3	588	94	1.80	+.171	593	82	1.86	+.300	0.92
brush-doe	13.6	602	86	—	—	613	85	—	—	—
blank-doe	17.8	608	102	0.17	-.053	634	118	1.31	-.254	0.15

* $p < .05$

neutral baseline conditions were 613 ms (SD = 85 ms) and 634 ms (SD = 118 ms) respectively. This difference was not significant; $F(1,19) = 1.31$, $r = -.254$.

The mean reaction time for the semantically related baseline condition was 593 ms (SD = 82 ms), and the difference between this baseline and the unrelated baseline was not significant; $F(1,19) = 1.86$, but the effect size (r) was +.300, indicating moderately strong facilitation for the semantically related baseline primes. The mean reaction time for the semantically related homophone condition was 572 ms (SD = 72 ms). The difference between this homophone condition and the unrelated baseline was significant; $F(1,19) = 10.68$, and the effect size (r) was +.600, indicating strong facilitation for the semantically related homophone primes. And finally, the mean reaction time for the phonologically mediated homophone condition was 622 ms (SD = 106 ms). The difference between this homophone condition and the unrelated baseline was also not significant; $F(1,19) = 0.25$, $r = -.114$. These last three results, taken together, indicate moderately strong priming effects for semantically related primes, but weak, or non-existent, priming effects for phonologically mediated primes; a result that once again speaks unfavorably for phonologically mediated priming.

The min F' Statistic

The difference between the "semantically related homophone" condition and the "unrelated baseline" condition was the only effect that proved significant for the min F' statistic; $F(1,64) = 4.74$. The effect sizes for the subject and item effects in this study are presented in Figure 10. Facilitation is clearly revealed by these effect sizes for each of the semantically related prime-target conditions, but no priming effects are apparent for the phonologically mediated prime condition.

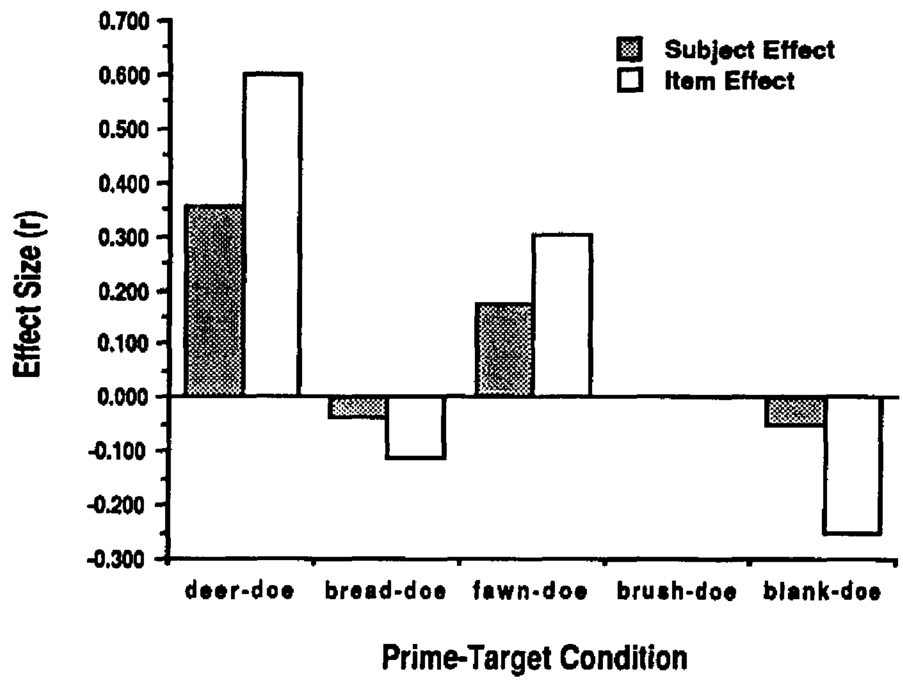

Figure 10. Effect size (r) plotted for each prime-target condition: Experiment 3, lexical decision task.

Naming Task

Method

Subjects

The subjects were 59 undergraduates enrolled in an Introductory Psychology course at the University of New Hampshire. The students received one laboratory credit toward a course requirement for their participation.

Stimuli

Because the naming task does not require non-words, the non-word targets were replaced with filler words. Otherwise, the stimuli were identical to those used in the lexical decision task.

Apparatus

The Apple Macintosh computer and the routines for controlling the presentation of stimuli were identical to those used for previous naming task experiments.

Procedure

The procedure was also identical to that used in previous naming tasks. The SOA was 250 ms, and the subjects were run individually. All responses were recorded onto tape and later digitized for analysis. At the conclusion of the experiment, the subjects were shown their data and debriefed.

Results and Discussion

Subject Effects

The semantically unrelated baseline condition yielded a mean reaction time of 420 ms (SD = 79 ms), and the neutral baseline condition yielded a mean reaction time of 420 ms (SD = 86 ms). The difference between these baselines was not significant; $F(1,58) = 0.00$, $r = .000$.

The semantically related baseline condition yielded a mean reaction time of 401 ms (SD = 51 ms). The difference between this baseline and the unrelated baseline was significant; $\underline{F}(1,58) = 6.95$, $\underline{r} = +.327$, indicating moderately strong facilitation for semantically related primes. The semantically related homophone condition yielded a mean reaction time of 402 ms ($\underline{SD}$ = 59 ms). The difference between this homophone condition and the unrelated baseline was also significant; $\underline{F}(1,58) = 7.92$, $\underline{r} = +.347$, indicating moderately strong facilitation for semantically related homophone primes. Finally, the phonologically mediated homophone condition yielded a mean reaction time of 407 ms ($\underline{SD}$ = 80 ms). The difference between this homophone condition and the unrelated baseline was not significant; $\underline{F}(1,58) = 3.12$, $\underline{r} = +.226$, but indicated moderate facilitation for phonologically mediated homophone primes. Taken together, these last three results indicate that semantically related homophones produce as much semantic priming as semantically related non-homophones, and there is also some evidence for phonologically mediated priming when the homophone serves as the target. The subject effects for this naming task appear in Table 6.

Item Effects

The item effects showed the same pattern of results as the subject effects, including a moderately strong effect for phonologically mediated primes. The item effects also appear in Table 6. The mean reaction times for the unrelated and neutral baseline conditions were 418 ms ($\underline{SD}$ = 50 ms) and 421 ms ($\underline{SD}$ = 44 ms) respectively. This difference was not significant; $\underline{F}(1,19) = 0.06$, $\underline{r} = -.056$.

The mean reaction time for the semantically related baseline condition was 402 ms ($\underline{SD}$ = 41 ms), but the difference between this baseline and the unrelated baseline was not significant; $\underline{F}(1,19) = 2.87$, and the effect size ($\underline{r}$) was +.362, indicating moderately strong facilitation for the semantically related

Table 6.

Naming Task Subject Effects, Item Effects, and min F' Statistics across Conditions in Experiment 3.

	Subject Effects				Item Effects				
Prime-Target	RT	SD	F(1,58)	r	RT	SD	F(1,19)	r	min F'
deer-doe	402	59	7.92*	+.347	403	47	1.26	+.250	1.09
bread-doe	407	80	3.12	+.226	402	48	1.88	+.300	1.17
fawn-doe	401	51	6.95*	+.327	402	41	2.87	+.362	2.03
brush-doe	420	79	—	—	418	50	—	—	—
blank-doe	420	86	0.00	+.000	421	44	0.06	-.056	0.00

* $p < .05$

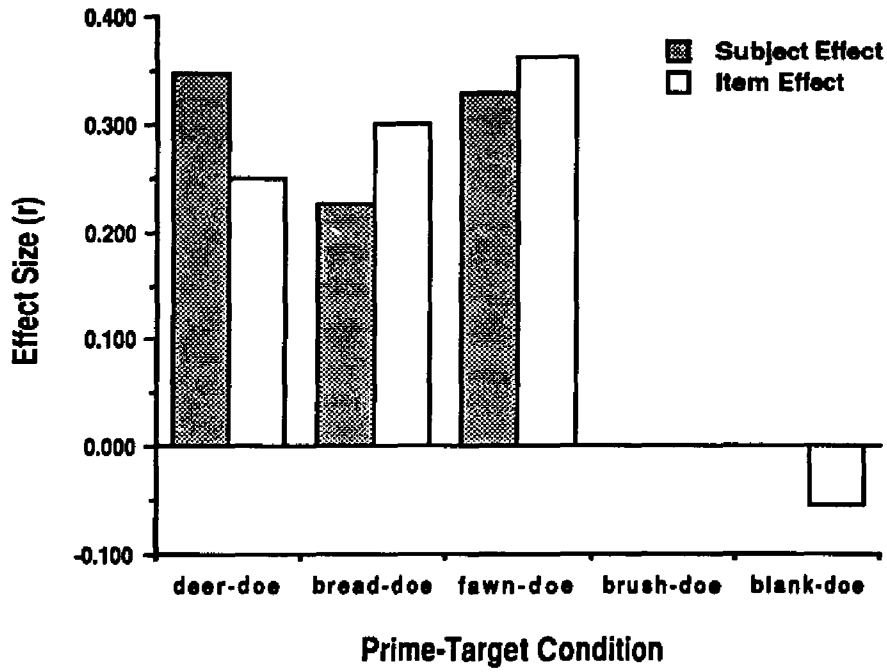

Figure 11. Effect size (r) plotted for each prime-target condition: Experiment 3, naming task

baseline primes. The mean reaction time for the semantically related homophone condition was 403 ms (SD = 47 ms), and the difference between this homophone condition and the unrelated baseline was also not significant; $F(1,19) = 1.26$, and the effect size (r) was +.250, indicating moderate facilitation for the semantically related homonym primes. And finally, the mean reaction time for the phonologically mediated homophone condition was 402 ms (SD = 48 ms). The difference between this homophone condition and the unrelated baseline was also not significant; $F(1,19) = 1.88$, $r = +.300$, again indicating moderately strong facilitation for phonologically mediated homophone primes.

The min F' Statistic

The min F' statistics for all comparisons appear in Table 6, but none of the comparisons reached significance. Figure 11 presents the effects sizes plotted for subject effects and item effects across prime-target conditions. Note that these results provide some tentative evidence for phonologically mediated priming when the homophone is used as the target in a naming task. This means that the prime "deer" somehow facilitates the subject's verbal response for the target "dough."

EXPERIMENT 4

Preview

In this final study, the automatic activation of dual semantic interpretations for homophones was investigated using auditorily presented primes. As in all previous studies, a lexical decision task and a naming task were used. Because homophones sound the same, they are ambiguous when presented auditorily. This should result in multiple semantic priming for concepts related to both members of the homophone pair. Given the failure to find phonologically mediated priming effects in Experiment 2 using visually presented homophones, it is important to establish that auditorily presented homophones can automatically activate multiple semantic interpretations in a cross-modal priming paradigm.

Lexical Decision Task

Method

Subjects

The subjects were 60 students enrolled in an Introductory Psychology course at the University of New Hampshire. The students each received one laboratory credit as part of a course requirement for their participation.

Stimuli

The stimuli were the same as those used in Experiment 2. For this experiment, the homophone primes were recorded and digitized for auditory presentation . This process made the semantically related homophones and the phonologically mediated homophones indistinguishable. These two conditions were therefore collapsed into a single condition consisting of semantically related homophones. The remaining baseline conditions were unchanged by the auditory mode of presentation. Appendix D contains the stimuli for this experiment. The non-word stimuli and the randomization procedures were identical to those used in Experiment 2.

Apparatus

Routines for controlling stimulus presentation and reaction time collection were the same as in preceding lexical decision tasks. Auditory presentation of the primes was accomplished by digitizing the recorded primes with a MacRecorder™ and storing them as sound files. These sound files were accessed by a subroutine called SPART which is part of a library of similar routines called PsychLib developed at Rice University (Lane & Ashby, 1987). The sound files were then sent through the headphone jack of the Macintosh SE to a Technics stereo receiver for playback through a pair of speakers.

Procedure

Each trial began with a fixation cross in the center of the screen. The duration of the fixation cross was 750 ms and it was followed by a blank screen which lasted 250 ms. The prime was then presented through the speakers. The delay between the onset of the auditory prime and the onset of the target was 1000 ms. With the auditory mode of prime presentation, measurement of the SOA is a problem because the duration of the auditory stimulus varies and the onset/offset of the stimulus is not discrete as it is in the case of a visual stimulus. Because the duration of the average auditory prime was around 650 ms (SD = 90 ms and a range from 494 ms to 794 ms), the average ISI was around 350 ms.

After the presentation of the prime, the target was presented for 250 ms. A millisecond timer was started upon the presentation of the target and was stopped upon the subject's response. Errors and reaction times were recorded in a data file containing all relevant stimulus and subject information.

After a brief pause, the fixation cross appeared and the next trial commenced. All other aspects of the procedure were the same as in previous lexical decision tasks

Subjects were run individually and each session lasted less than one half hour. Subjects were told that the experiment was concerned with the speed and accuracy with which they could discriminate words from non-words. The practice set was then presented, followed by the two experimental sets with brief breaks in between while each new set was randomized. When the last set was completed, the subjects were shown their data and a debriefing statement was provided.

Results and Discussion

The baseline conditions in this experiment provide anchor points against which the priming effects of the auditorily presented homophones can be measured. If multiple semantic priming occurs within 250 ms, then the priming effect for the homophone primes should be equivalent to the priming effect for the semantically related non-homophone primes. The semantically unrelated primes and the neutral primes represent baselines where, by definition, no priming exists. There should be no difference between the semantically unrelated baseline and the neutral baseline.

Error Rates

The percentage of errors was highest in the semantically unrelated baseline condition, 16.8%, and lowest in the semantically related baseline condition, 4.2%. The neutral baseline condition and the homonym condition produced error rates of 4.6% and 6.1% respectively.

Subject Effects

The semantically unrelated baseline condition yielded a mean reaction time of 572 ms (SD = 88 ms), and the neutral baseline condition yielded a mean reaction time of 565 ms (SD = 77 ms). The difference between these baselines was not significant; F(1,59) = 0.34, and the effect size (r) was +.076.

The semantically related baseline condition yielded a mean reaction time of 531 ms (SD = 65 ms). The difference between this baseline and the unrelated baseline was significant; F(1,59) = 11.90, r = +.410, indicating strong facilitation for the semantically related primes. The homophone condition yielded a mean reaction time of 544 ms (SD = 65 ms). The difference between this experimental condition and the unrelated baseline was also significant; F(1,59) = 6.71, r = +.320, indicating strong facilitation for semantically related homophone primes. In addition, the difference between the homophone condition and the semantically related condition was not significant; F(1,59) = 2.83. These last three results indicate that homophones presented auditorily produce as much semantic priming as non-homophones. Table 7 presents these results for the subject effects.

Item Effects

The item effects were found to be similar to the subject effects and they are presented in Table 7 as well. The mean reaction times for the unrelated and neutral baseline conditions were 583 ms (SD = 69 ms) and 568 ms (SD = 51 ms) respectively. This difference was not significant; F(1,19) = 1.37, and the effect size (r)was +.260.

The mean reaction time for the related baseline condition was 535 ms (SD = 43 ms). The difference between the related and unrelated baseline conditions was significant; F(1,19) = 17.29, r = +.690, indicating extremely strong facilitation for the semantically related primes. The mean reaction time for the homophone condition was 545 ms (SD = 43 ms). The difference between the homophone condition and the unrelated baseline

Table 7.

Lexical Decision Error Rates, Subject Effects, Item Effects, and min F' Statistics across Conditions in Experiment 4.

		Subject Effects				Item Effects				
Prime-Target	ER(%)	RT	SD	F(1,59)	r	RT	SD	F(1,19)	r	min F'
/dō/-deer	6.1	544	65	6.71*	+.320	545	43	8.42*	+.554	3.73
/fawn/-deer	4.2	531	65	11.90*	+.410	535	43	17.29*	+.690	7.05*
/yeast/-deer	16.8	572	88	—	—	583	69	—	—	—
/blank/-deer	4.6	565	77	0.34	+.076	568	51	1.37	+.260	0.27

* $p < .05$

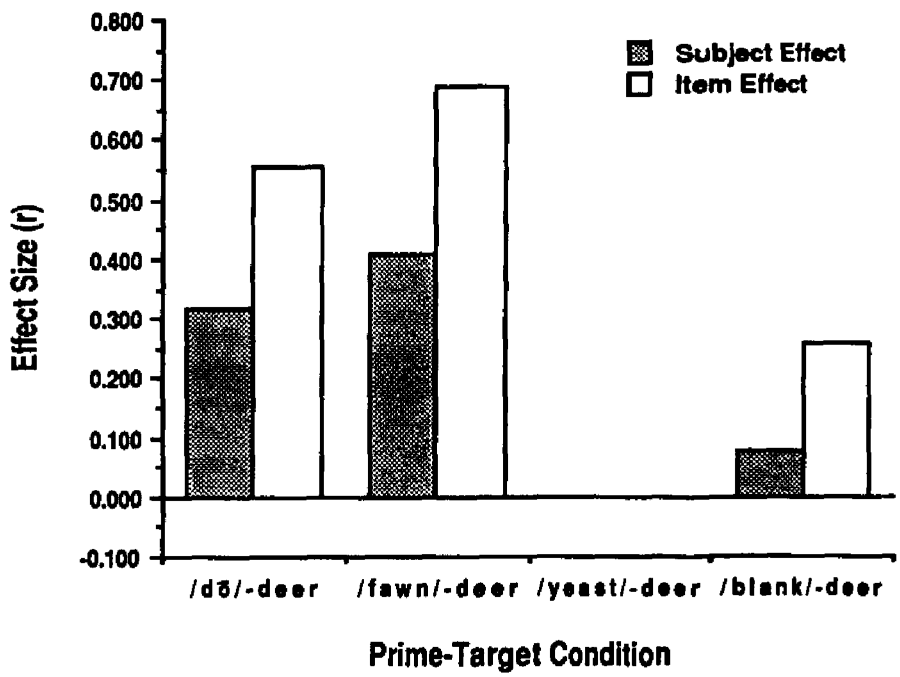

Figure 12. Effect size (r) plotted for each prime-target condition: Experiment 4, lexical decision task.

condition was also significant; $F(1,19) = 8.42$, $r = +.554$, indicating very strong facilitation for semantically related homophones. And finally, the difference between the homophones and the semantically related baseline was not significant; $F(1,19) = 2.00$. Again, these results indicate that homophones produce as much semantic priming as non-homophones.

The min F' Statistic

Comparing the semantically related baseline with the unrelated baseline, the min F' statistic was significant; $F(1,68) = 7.05$. In addition, the min F' for the difference between the homophone condition and the unrelated baseline was nearly significant; $F(1,64) = 3.73$. Considering the fact that the min F' statistic is an extremely stringent test, these results provide strong evidence for multiple semantic priming when homophones are used as auditory primes in a lexical decision task. Figure 12 presents a graph plotting the effect sizes for each prime-target condition.

Naming Task

Method

Subjects

The subjects were 59 students enrolled in an Introductory Psychology course at the University of New Hampshire. Each student received one laboratory credit toward a course requirement for their participation.

Stimuli

Except for the fact that the naming task does not require non-words, the stimuli were the same as in the lexical decision task. The auditorily presented primes as well as the practice trials and filler trials also remained the same as those in the lexical decision task.

Apparatus

The routines that controlled the stimulus presentation and data collection for this experiment were written in HyperTalk. The auditory primes were digitized and stored as "snd" resources in the HyperCard stack. The program accessed these "snd" resources when called by the PLAY "snd" statement. The sounds were sent through the Macintosh SE headphone jack to a stereo receiver for playback through a pair of speakers. Upon the presentation of each target word, an inaudible beep was sent to a Technics tape deck and recorded. The subject's responses for each trial were also recorded on the tape using a microphone. The tapes were later digitized as in previous naming tasks and the naming latencies were obtained by measuring the interval between the onset of the "beep" and the onset of the subject's voice on the tape.

Procedure

The procedure was the same as that used in the lexical decision task. Subjects were run individually and each session lasted less than one half hour. They were told that the experiment was concerned with the speed and accuracy with which they could pronounce words. The practice set was then presented, followed by the two experimental sets with brief breaks in between. When the last set was completed, the subjects were shown their data and a debriefing statement was provided.

Results and Discussion

Subject Effects

The semantically unrelated baseline condition yielded a mean reaction time of 379 ms (*SD* = 61 ms), and the neutral baseline condition yielded a mean reaction time of 381 ms (*SD* = 57 ms). The difference between these baselines was not significant; $F(1,58) = 0.18$, and the effect size (r) was -.056.

The semantically related baseline condition yielded a mean reaction time of 358 ms (SD = 61 ms). The difference between this baseline and the unrelated baseline was significant; $F(1,58) = 14.53$, $r = +.448$, indicating strong facilitation for the semantically related primes. The homophone condition yielded a mean reaction time of 368 ms (SD = 55 ms). The difference between this experimental condition and the unrelated baseline was also significant; $F(1,58) = 7.61$, $r = +.341$, indicating moderately strong facilitation for homophone primes. In addition, the difference between the homophone condition and the semantically related condition was significant; $F(1,58) = 4.74$. These results indicate that strong semantic priming effects are present for both homophones and non-homophones. Table 8 presents these results for the subject effects.

Item Effects

The item effects were also found to be quite strong for both homophones and non-homophones. They are presented in Table 8 as well. The mean reaction times for the unrelated and neutral baseline conditions were 379 ms (SD = 42 ms) and 382 ms (SD = 40 ms) respectively. This difference was not significant; $F(1,19) = 0.09$, and the effect size (r) was -.069.

The mean reaction time for the related baseline condition was 358 ms (SD = 49 ms). The difference between the related and unrelated baseline conditions, however, was not significant; $F(1,19) = 4.22$, $r = +.426$. The mean reaction time for the homophone condition was 368 ms (SD = 38 ms). The difference between the homophone condition and the unrelated baseline condition was also not significant; $F(1,19) = 0.96$, $r = +.219$. And finally, the difference between the homophones and the semantically related baseline was not significant; $F(1,19) = 0.94$. Again, these results indicate moderate semantic

Table 8.

Naming Task Subject Effects, Item Effects, and min F' Statistics across Conditions in Experiment 4.

	Subject Effects				Item Effects				
Prime-Target	RT	SD	F(1,58)	r	RT	SD	F(1,19)	r	min F'
/dō/-deer	368	55	7.61*	+.341	368	38	0.96	+.219	0.85
/fawn/-deer	358	61	14.53*	+.448	358	49	4.22	+.426	3.27
/yeast/-deer	379	61	---	---	379	42	---	---	---
/blank/-deer	381	57	0.18	-.056	382	40	0.09	-.069	0.06

* $p < .05$

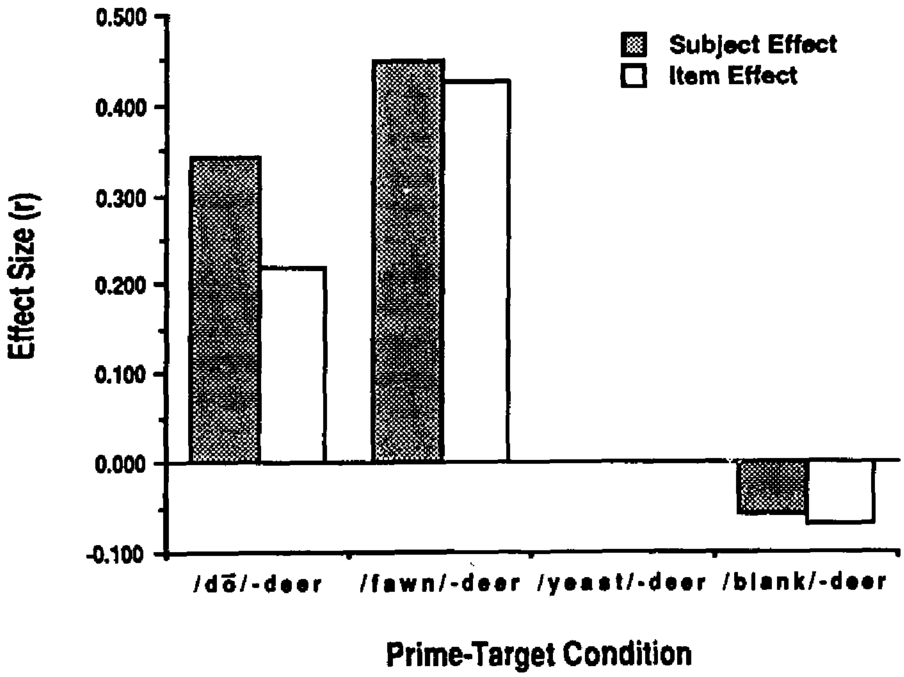

Figure 13. Effect size (r) plotted for each prime-target condition: Experiment 4, naming task.

priming effects for homophones and non-homophones in a naming task with auditory primes.

The min F' Statistic

Because none of the item effects proved significant, min F' statistics were not computed. Figure 13 presents a graph plotting the effect sizes for each prime-target condition. Facilitation is clearly present for both meanings of the auditorily presented homophones in this naming task.

GENERAL DISCUSSION

Overview

The purpose of the present study was to investigate the role of phonology in word recognition. Several models of word recognition posit that printed words are converted into a phonological code prior to lexical access, while other models posit that phonological codes are activated following lexical access via an orthographic code. In the former models, the locus of the effect of the phonological code is pre-lexical, while in the latter models, the locus of the effect of the phonological code is post-lexical. Because pre-lexical models and post-lexical models both predict phonologically mediated priming effects, the failure to find phonologically mediated priming effects in the present investigation indicates that we must reconsider the role of phonology in models of printed word recognition.

Summary of Results

Four experiments were conducted to determine the extent to which lexical priming effects are mediated by a phonological code. Each priming experiment was run using a lexical decision task and a naming task. Each experiment also employed a 250 ms SOA between the prime and the target. This SOA was chosen because automatic priming effects due to spreading activation are found to be strongest within 250 ms after the presentation of the prime. In addition, multiple semantic priming effects are also strongest at the 250 ms SOA (Simpson & Burgess, 1985). The results of Experiments 1 and 4 will be examined first because both of these studies pertain to the issue of multiple semantic priming.

Homonyms such as "mint" were used in Experiment 1 to verify that both meanings of an ambiguous word are activated automatically upon presentation.

The multiple semantic priming effects observed in the lexical decision task were comparable to those found by Simpson and Burgess (1985). In a priming paradigm with a 250 millisecond SOA, the homonym "mint" was found to facilitate the recognition of words related to both interpretations such as "candy" and "coin." This effect was strong in the lexical decision task, but it was weak in the naming task. The failure to demonstrate multiple semantic priming with the naming task is difficult to interpret because the expected semantic priming effects in the naming task were also weak.

In Experiment 4, homophones such as "dough" and "doe" served as primes in a cross-modal priming paradigm similar to Swinney (1979). When the homophones were made ambiguous through auditory presentation, the homophone "dough" was found to facilitate the recognition of words related to both interpretations such as "deer" and "bread." These multiple semantic priming effects were evident in both the lexical decision task and the naming task. These results again support the view that concepts related to multiple meanings are activated automatically upon the presentation of an ambiguous word. Furthermore, these results can be taken as evidence for phonologically mediated priming because the homophones in this experiment were presented auditorily. As convincing as this evidence may be for the role of phonology in auditory word recognition and priming, it does not reveal whether phonology mediates lexical access during visual word recognition. Experiments 2 and 3 deal with the role of phonology in visual word recognition because they examine phonologically mediated priming effects that result from the visual presentation of a homophone prime.

In Experiment 2, a homophone prime such as "dough" was followed by the presentation of a target word that was either semantically related to the prime (e.g., "bread") or mediated by the phonological code for the prime (e.g., "deer"). Priming effects were found for target words that were semantically related to the prime, but not for target words that were mediated by the phonological code. The failure to find phonologically mediated priming effects was corroborated in both the lexical decision task and the naming task.

The results of Experiment 2, taken together, provide no evidence for phonologically mediated priming and therefore they call into question the role of phonology in printed word recognition. Because "dough" and "doe" are orthographically distinctive, lexical access and priming occur only for concepts related to the word specified by the orthography. This means that it is primarily orthography that determines which concepts are activated in the lexicon and, therefore, which concepts are semantically primed. Even though homophones share the same phonological code, phonology appears to be quite limited in its effects on visual word recognition and priming when homophones are used as primes.

Experiment 2 is critical for the argument that phonology plays a very limited role in lexical access, and an important component of this argument is the use of the r statistic as a measure of the size of the phonologically mediated priming effect. By calculating the effect size, it was possible to determine that the phonologically mediated priming effect was extremely weak relative to the semantic priming effects found in the baseline conditions. Note that a weak effect size does not prove that phonology does not play any role in lexical access. However, the use of the effect size does admit the conclusion that the impact of phonology upon lexical access is small relative to the effects of orthography.

In Experiment 3, the primes and targets used in Experiment 2 were reversed. Thus, the homophone "dough" served as the target and the visually presented prime was either semantically related (e.g., "bread") or mediated by a phonological code (e.g., "deer"). This reversal was motivated by the suggestive findings of VanOrden (1987, 1988) in which homophone targets (e.g., "dough") were misclassified (i.e., as instances of the category, "a female deer") in a category verification task. VanOrden argued persuasively that this misclassification was due to the pre-lexical generation of a phonological code for the homophone target (e.g., "dough") which was then confused with the correct instance of the category (e.g., "doe"). It should be noted, however, that subjects responded correctly over 75% of the time, indicating that they are sensitive to the orthographic differences between "dough" and "doe," and that they can then use this information to respond correctly. In addition, VanOrden found longer response latencies for the homophone substitutions, indicating that the categorical prime, "a female deer," actually inhibited the response to the homophone target, "dough." Contrary to VanOrden's conclusions, these results can actually be used as evidence against the pre-lexical generation of a phonological code.

In the lexical decision task of Experiment 3, strong priming effects were observed when the prime (e.g., "bread") was semantically related to the homophone target (e.g., "dough"). In addition, when the prime (e.g., "deer") was mediated by the phonological code for the target (e.g. "dough"), no priming effects were observed. These results for the lexical decision task are in accord with the results of Experiment 2, and they provide further evidence for the claim that lexical access is not mediated by a phonological code.

Turning to the naming task of Experiment 3, strong priming effects were again observed for the semantically related primes, indicating that the prime "bread" facilitates the pronunciation of "dough." The results of the naming task, however, diverge from previous results when we consider the effect of phonologically mediated priming. If the subject is required to pronounce the homophone "dough," their response is actually facilitated by the presentation of the prime "deer." This result is quite surprising given the fact that no other experiments have demonstrated evidence for priming effects mediated by a phonological code.

Taken together, the results of Experiment 3 indicate that when the task involves a lexical decision, the word "deer" does not facilitate the response to the phonologically mediated target "dough." But, when the response involves pronunciation (i.e., explicit generation of phonological/articulatory codes), the word "deer" does facilitate the pronunciation of the phonologically mediated target "dough." This priming effect in the naming task, however, may not be due to the pre-lexical generation of a phonological code. We must, therefore, take a closer look at the phonological code that seems to be responsible for this effect in order to determine whether the code is generated before or after lexical access (i.e. during the recognition stage versus during the pronunciation stage).

The fact that the phonologically mediated priming effect only occurs in the naming task of Experiment 3 seems to indicate that there is something special happening when the subject must pronounce the word "dough." It is also important to remember that the homophone is not the prime in this experiment, and therefore, the priming effect is being generated by the word "deer." Because the word "deer" activates semantically related concepts such as "fawn" and "doe," the facilitation observed for the pronunciation of "dough" is probably due to the activation of the concept node "doe," which just so happens to have the same phonological/articulatory code as "dough." When the concept node "doe" is activated, the phonological/articulatory code for "doe" becomes available to assist in the pronunciation of the target word "dough." Thus, the phonological code that assists in the pronunciation of the homophone target (e.g., "dough") is generated by the activation of a concept node in the lexicon (e.g. "doe").

This argument is quite complex, but the priming effect for the naming task is rather surprising and it is difficult to understand why it should arise only when the homophone is the target word and the task involves pronunciation. This combination of factors makes it difficult to suppose that a pre-lexically generated phonological code was responsible for this priming effect. The fact that no facilitation effects were found in the lexical decision task also indicates that whatever the code is that produces the phonologically mediated priming effect in the naming task, it is not generated prior to lexical access.

The argument that the priming effects in Experiment 3 are due to post-lexical facilitation during the pronunciation stage receives further support from a study by Balota, Boland, and Shields (1989) in which they demonstrated that priming effects can occur during the pronunciation phase of a naming task. Balota et al. presented words (e.g., "dog") to subjects and told them to say the words as quickly as possible as soon as a cue was presented. The cue for pronunciation of the word "dog" was either a sequence of Xs (e.g., "xxx"), a semantically unrelated word (e.g., "cup"), or a semantically related word (e.g., "cat"). Subjects were found to pronounce the word "dog" faster if the cue was semantically related. Balota et al. argued that this effect could not be the result of facilitation during the process of pattern recognition for the word "dog" because the subjects had been viewing the word for more than one second prior to the onset of the cue. Instead, this effect could only be due to facilitation during the pronunciation phase because the semantically related cue provided further activation for the concept "dog" which assisted in the pronunciation of the word "dog." These results can be applied to the results of the naming task in Experiment 3 by assuming that subjects were quicker to pronounce the word "dough" because the word "deer" had somehow primed the phonological code for "doe" (e.g., /dō/).

Returning to the inhibitory effects observed by VanOrden in the category verification task, it may be plausibly argued that these effects were the result of a post-lexically generated phonological code which interfered with the decision processes involved in category verification. Although the category verification task clearly involves lexical access, the decision stage of this task is quite complicated and time-consuming -- response latencies observed by VanOrden were around 950 ms as compared to around 550 ms in the lexical decision tasks and 430 ms in the naming tasks in the present study. The fact that the category verification task requires almost twice as much time to complete as the lexical decision and naming tasks implies that plenty of time is available for post-lexically generated phonological codes to produce their inhibitory effects on the response latency measure. Furthermore, if phonological codes are generated pre-lexically, then facilitation should be predicted instead of inhibition (i.e., the word "deer" should facilitate the response to "dough"). Based upon these arguments, the effects observed by VanOrden in the category verification task, are probably due to post-lexically generated phonological codes.

The results of the present series of experiments indicate that phonology plays a role in lexical access when the homophone is presented auditorily, and that post-lexically generated phonological codes play a role when the homophone must be pronounced; but the present experiments also reveal that phonology does not play a role in lexical access when the homophone is presented visually, or when the response does not involve pronunciation. These results suggest that there is a strict limitation on the role of phonology in printed word recognition. In the next section, I would like to evaluate the effect of this limitation on the several models of word recognition that posit phonologically mediated routes to the lexicon.

Reconsidering the Role of Phonology in Lexical Access

The failure to demonstrate phonologically mediated priming in the present experiments is disconcerting when we consider the amount of effort expended during the past two decades to develop models that posit the generation of a phonological code prior to lexical access. The idea that phonology plays a role in reading has been assumed ever since researchers began thinking about reading skills (Huey, 1908). Although few attempts prior to Rubenstein et al. (1971) were made to explicitly determine whether phonology was involved in lexical access, this assumption has shaped the models of reading and the empirical questions that researchers have asked over the last two decades.

It is clear that any model of word recognition that postulates the pre-lexical generation of a phonological code is called into question when we consider the failure to demonstrate phonologically mediated priming in the present investigation. In the next few paragraphs, I would like to evaluate anew the models of word recognition that posit pre-lexical effects of phonological codes (e.g., the indirect phonological route model, the dual-route model, and the interactive-activation model). I will then present the only model of lexical access that provides a plausible account for the present data by postulating that orthography is the primary route to the lexicon.

One model of word recognition that is not supported by the present results is the indirect phonological route model (see Figure 3). This model predicts phonologically mediated priming effects that are as strong as semantic priming effects. In other words, this model predicts the equivalent of multiple semantic priming for visually presented homophones. This model is clearly not supported by the present results.

A second model that is not fully supported by the present results is the dual-route model (see Figure 4). According to this model, phonological codes as well as orthographic codes are involved in lexical access. If we assume that phonological codes are generated rapidly enough to compete with orthographic codes for the activation of lexical entries, then this model predicts phonologically mediated priming effects. As pointed out previously, these effects should not be quite as strong as those predicted for semantic priming effects. However, the failure to find even weak effects for phonologically mediated priming suggests either a) that lexical access does not involve a phonological route, or b) that the phonological route to the lexicon is too slow to exert any priming effects when the SOA is set at 250 ms. The dual-route model can be salvaged if the latter possibility is true. One way to assess the possibility that the phonological route is considerably slower than the orthographic route is to use a longer SOA, 500 ms for example. Longer SOAs were planned in the present investigation, but due to limited resources, these SOAs were not employed. Longer SOAs would certainly provide ample time for the generation of the phonological code, but it is hard to imagine what purpose would be served by a phonological code that is generated long after lexical access has been achieved by the orthographic code. Furthermore, phonological codes can be generated very rapidly under most ordinary reading conditions as evidenced by the response latencies in the naming task. The dual-route model can be salvaged by positing that the phonological route is simply slow and prone to errors, but this would be accomplished at the expense of any meaningful role for phonology in lexical access because the generation of the phonological code would be too slow and unreliable to exert any reasonable effects upon lexical access.

A third model that receives minimal support from the present results is the interactive-activation model (see Figure 5). This model makes very similar predictions to the dual-route model (i.e., moderately small effects for phonologically mediated priming are predicted). Again, however, the failure to find even weak effects for phonologically mediated priming suggests either a) that phonological units do not contribute to the activation of lexical entries during lexical access, or b) that, as in the dual-route model, these units are slow to exert their influence on lexical access. The interactive-activation model can easily be made to conform to the present results either by eliminating the phonological units from the lexical access process, or by slowing their rate of activation. Models such as the dual-route model and the interactive-activation model are difficult to refute because they are flexible enough to accommodate even blatantly disconfirmatory results by altering one of several parameters that are free to vary widely. If these models are reasonably constrained, however, they cannot accommodate the present results.

Based upon the data at hand, it is tempting to argue that the only model of lexical access that can account for the failure to find phonologically mediated priming in the present investigation is the direct orthographic route model. It is certainly ironic that the direct orthographic route model remains by default the only viable model of word recognition because it does not postulate that phonological codes will influence lexical access. In retrospect, it does not seem like much progress has been made by postulating that phonological codes assist in lexical access for printed words. To understand how this hypothesis has managed to generate support among reading researchers in the face of such profound difficulties in finding empirical support, it is necessary to return to the beginning and try to understand how reading skills are acquired in the first place.

Future Directions and Considerations

The question of whether phonology plays a role in lexical access began by considering how children acquire reading skills. If children cannot somehow convert print to sound, then it seems that they would have difficulty learning to read, given the fact that their knowledge of language is derived entirely from spoken communication. How do we reconcile this apparent need for phonology in reading skill acquisition with the convincing evidence that college freshmen do not make use of phonology in lexical access?

One way to determine whether children employ phonological codes in lexical access would be to replicate the present priming experiments with children. Perhaps children will show phonologically mediated priming effects where college freshmen do not. If children convert the word "dough" into its phonological code /dō/ prior to figuring out its meaning, then priming effects should be observed for target words like "deer" and "fawn." Furthermore, if the use of phonological codes in lexical access declines as children mature, then a decline in the effects of phonologically mediated priming would be predicted similar to the decline in the homophone substitution errors found by Doctor and Coltheart (1980) in children ages 6 to 10.

Another way to determine whether phonological codes play a central role in learning to read would be to use unfamiliar homophones. If college freshmen are not familiar with the orthography of a particular word, then they will probably be forced to generate a phonological code to assist in lexical access just as children must do when they encounter an unfamiliar word. Under such circumstances it might also be possible to observe phonologically mediated priming effects because the lack of familiar orthography will not constrain lexical access as thoroughly as it does when the homophone is familiar. Note also that the homophones chosen for use in the present investigation were chosen specifically because they were familiar to college freshmen.

Familiarity for words is directly related to the probability that the orthographic code for a word is firmly established in the lexicon. Once a word becomes familiar, it can be plausibly argued that the orthography for that word will play a larger role in lexical access. Eventually, the word may become so familiar that lexical access can be achieved by the orthographic code alone. Furthermore, it is likely that very little exposure to an unfamiliar word is necessary before its orthographic code becomes firmly established in the lexicon. Thus, phonologically mediated priming effects may be observed only when the word is very unfamiliar and therefore when no orthographic code is present in the lexicon at all. In this case, lexical access is mediated by a phonological code only because no orthographic code yet exists.

The preceding arguments are intended to suggest that phonological codes can be generated for words and non-words that have never been seen before, and that these phonological codes can be used to access meaning. After relatively brief exposure to the orthography for a word, however, an orthographic code will be established in the lexicon for future use in lexical access. In this way, lexical access will typically involve the use of the orthographic code, especially when the orthography is highly familiar, but occasionally lexical access will be achieved by generating a plausible phonological code for an orthographically unfamiliar word. The present investigation has shown clearly that lexical access for familiar words is primarily determined by orthographic codes and that the role of phonology is quite minimal. It remains for future investigations to determine how unfamiliar the orthography of a word must be before lexical access requires the generation of a phonological code.

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APPENDICES

APPENDIX A

Homonym Stimuli Used in Experiment 1.

Target	Prime: Semantically Related Homonym	Semantically Related Control	Semantically Unrelated Control	Neutral
ant	bug	insect	secret	blank
spy	bug	secret	insect	blank
candy	mint	cookie	nickel	blank
coin	mint	nickel	cookie	blank
thumb	palm	finger	beach	blank
coconut	palm	beach	finger	blank
tobacco	pipe	leaf	sludge	blank
sewer	pipe	sludge	leaf	blank
eye	pupil	nose	teacher	blank
student	pupil	teacher	nose	blank
clothes	iron	shirt	chrome	blank
steel	iron	chrome	shirt	blank
river	bank	stream	cash	blank
money	bank	cash	stream	blank
piano	organ	concert	lung	blank
kidney	organ	lung	concert	blank
acorn	nut	oak	wrench	blank
bolt	nut	wrench	oak	blank
peach	pit	plum	dig	blank
hole	pit	dig	plum	blank

APPENDIX B

Homophone Stimuli Used in Experiment 2.

	Prime				
Target	Semantically Related Homophone	Phonologically Mediated Homophone	Semantically Related Control	Semantically Unrelated Control	Neutral
deer	doe	dough	fawn	yeast	blank
bread	dough	doe	yeast	fawn	blank
ocean	whale	wail	crab	shout	blank
scream	wail	whale	shout	crab	blank
baker	flour	flower	oven	rose	blank
tulip	flower	flour	rose	oven	blank
rabbit	hare	hair	carrot	brush	blank
comb	hair	hare	brush	carrot	blank
armor	knight	night	shield	noon	blank
morning	night	knight	noon	shield	blank
clam	mussel	muscle	oyster	skin	blank
bone	muscle	mussel	skin	oyster	blank
paddle	oar	ore	canoe	steel	blank
iron	ore	oar	steel	canoe	blank
queen	reign	rain	prince	thunder	blank
cloud	rain	reign	thunder	prince	blank
hotel	suite	sweet	inn	syrup	blank
sugar	sweet	suite	syrup	inn	blank
hips	waist	waste	legs	junk	blank
garbage	waste	waist	junk	legs	blank

APPENDIX C

Homophone Stimuli Used in Experiment 3.

Target	Prime: Semantically Related Homophone	Phonologically Mediated Homophone	Semantically Related Control	Semantically Unrelated Control	Neutral
doe	deer	bread	fawn	brush	blank
dough	bread	deer	yeast	shield	blank
whale	ocean	scream	crab	fawn	blank
wail	scream	ocean	shout	noon	blank
flour	baker	tulip	oven	oyster	blank
flower	tulip	baker	rose	junk	blank
hair	comb	rabbit	brush	yeast	blank
hare	rabbit	comb	carrot	thunder	blank
night	morning	armor	noon	oven	blank
knight	armor	morning	shield	crab	blank
mussel	clam	bone	oyster	carrot	blank
muscle	bone	clam	skin	syrup	blank
ore	iron	paddle	steel	shout	blank
oar	paddle	iron	canoe	rose	blank
rain	cloud	queen	thunder	canoe	blank
reign	queen	cloud	prince	inn	blank
sweet	sugar	hotel	syrup	legs	blank
suite	hotel	sugar	inn	skin	blank
waste	garbage	hips	junk	prince	blank
waist	hips	garbage	legs	steel	blank

APPENDIX D

Homophone Stimuli Used in Experiment 4.

	Prime			
Target	Semantically Related Homophone	Semantically Related Control	Semantically Unrelated Control	Neutral
deer	doe/dough	fawn	yeast	blank
bread	dough/doe	yeast	fawn	blank
ocean	whale/wail	crab	shout	blank
scream	wail/whale	shout	crab	blank
baker	flour/flower	oven	rose	blank
tulip	flower/flour	rose	oven	blank
rabbit	hare/hair	carrot	brush	blank
comb	hair/hare	brush	carrot	blank
armor	knight/night	shield	noon	blank
morning	night/knight	noon	shield	blank
clam	mussel/muscle	oyster	skin	blank
bone	muscle/mussel	skin	oyster	blank
paddle	oar/ore	canoe	steel	blank
iron	ore/oar	steel	canoe	blank
queen	reign/rain	prince	thunder	blank
cloud	rain/reign	thunder	prince	blank
hotel	suite/sweet	inn	syrup	blank
sugar	sweet/suite	syrup	inn	blank
hips	waist/waste	legs	junk	blank
garbage	waste/waist	junk	legs	blank

APPENDIX E

Non-Word and Filler Stimuli for Experiment 1.

Lexical Decision Task

Homonyms		Non-Homonyms		Neutral	
Prime	Target	Prime	Target	Prime	Target
plane	fouch	bicycle	jalt	blank	plame
mold	pagel	castle	farris	blank	marple
toast	crafe	gown	heney	blank	shart
bear	plass	stars	brust	blank	lipe
pool	grent	pike	scaul	blank	aden
		store	tem		
		pear	lart		
		machine	vauld		
		copper	calin		
		flag	bew		

Naming Task

Homonyms		Non-Homonyms		Neutral	
Prime	Target	Prime	Target	Prime	Target
plane	couch	bicycle	jam	blank	plant
mold	bagel	castle	farm	blank	maple
toast	crate	gown	honey	blank	shark
bear	grass	star	cloak	blank	pencil
pool	grain	pike	thief	blank	bag
		store	trout		
		pear	lark		
		machine	trumpet		
		copper	fence		
		flag	mist		

APPENDIX F

Non-Word and Filler Stimuli for Experiments 2 through 4.

Lexical Decision Task

Homophones		Neutral		Non-Homophones	
Prime	Target	Prime	Target	Prime	Target
plain	fouch	blank	shart	store	tem
bough	crafe	blank	marple	peach	lart
urn	grent	blank	lipe	copper	calin
beech	rolt	blank	heney	bicycle	jalt
bear	plame			machine	vauld
steak	jume			castle	farris
yolk	bresh			gown	pagel
maid	plass			star	bew

Naming Task

Homophones		Neutral		Non-Homophones	
Prime	Target	Prime	Target	Prime	Target
bear	pencil	blank	shark	store	trout
steak	mist	blank	maple	peach	lark
yolk	bed	blank	bag	copper	fence
maid	grass	blank	honey	bicycle	jam
plain	couch			machine	trumpet
bough	thief			castle	farm
urn	grain			gown	egg
beech	cloak			star	planet

APPENDIX G

Practice Sets used for All Experiments.

Lexical Decision Task.

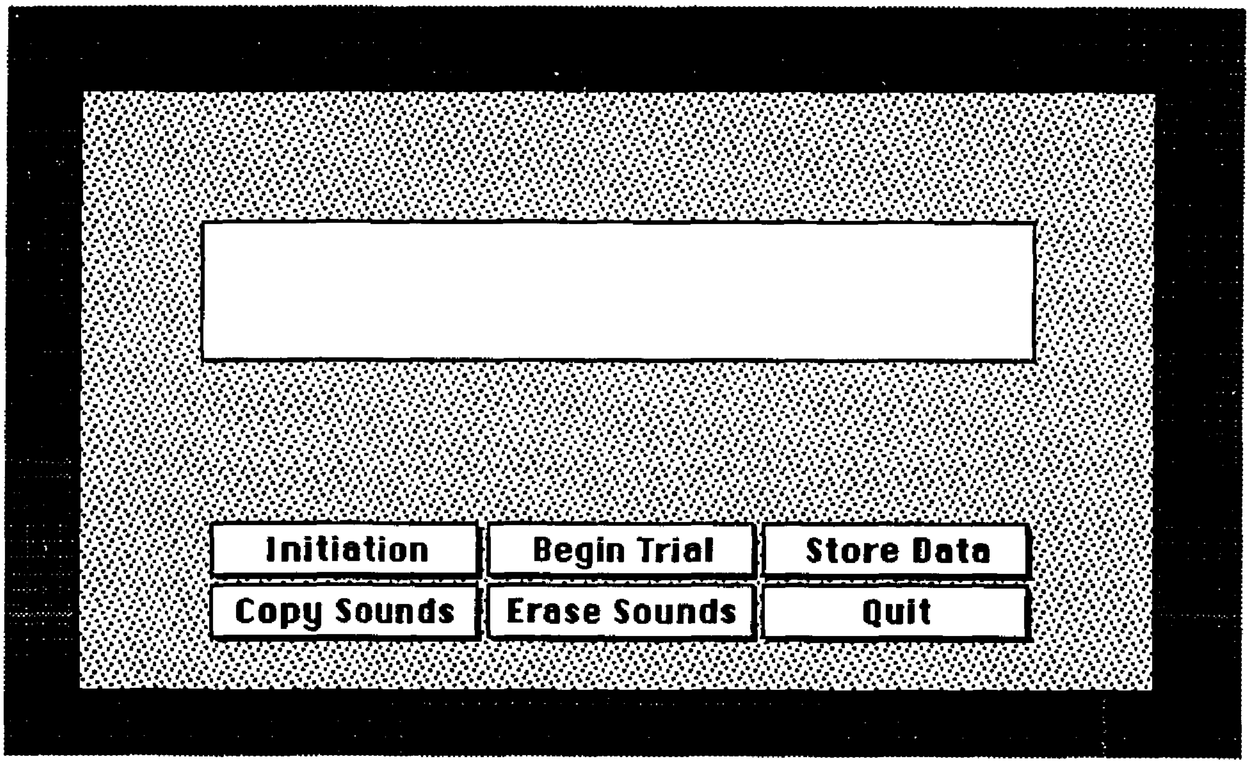
Prime	Target
tiger	hill
harp	sand
blank	fish
blank	spring
brick	toaster
dragon	stune
ink	greel
rock	plact
blank	leask
blank	courp
duck	plow
picture	heart
lake	chair
fiddle	marsh
blank	carpet
ring	lorup
pill	fald
witch	choat
passage	horbel
blank	rast

Naming Task.

Prime	Target
tiger	hill
harp	sand
blank	fish
blank	spring
brick	toaster
dragon	stone
ink	green
rock	plate
blank	leaf
blank	court
duck	plow
picture	heart
lake	chair
fiddle	marsh
blank	carpet
ring	cow
pill	goose
witch	coat
passage	hand
blank	mast

APPENDIX H

HyperCard Screen Used for Naming Task Program.



HyperTalk Script for the "Initiation" Routine.

```
on mouseUp
  play "Crystal"
  hide menubar
  hide cd fld "stimuli"
  hide cd fld "random"
  hide cd fld "data"
  hide cd fld "cross"
  hide cd fld "prime"
  hide cd fld "target"
  hide cd fld "RT"
  hide cd fld "initials"
  hide cd fld "experiment"
  hide cd fld "set"
  hide cd fld "sounds"
  put empty into cd fld "stimuli"
  put empty into cd fld "random"
  put empty into cd fld "cross"
```

```
put empty into cd fld "prime"
put empty into cd fld "target"
put empty into cd fld "RT"
put empty into cd fld "initials"
put empty into cd fld "experiment"
put empty into cd fld "set"
put empty into cd fld "sounds"
put 0 into buff
repeat until buff = 1
  ask "What are your initials?"
  put it into card field "initials"
  show cd fld "initials"
  ask "What set number do you wish? (1,2,or 0)"
  put it into cd fld "experiment"
  show cd fld "experiment"
  ask "What stimulus set do you wish? (A thru E)"
  put it into cd fld "set"
  show cd fld "set"
  answer "Is everything OK?" with "Redo" or "OK"
  if it is "OK" then
    hide cd fld "initials"
    hide cd fld "experiment"
    hide cd fld "set"
    put 1 into buff
  end if
end repeat
put "I'm randomizing the stimuli." into cd fld "cross"
show cd fld "cross"
wait 30
hide cd fld "cross"
if cd fld "experiment" = 1 then
  if cd fld "set" = "A" then
    open file "2A1"
    read from file "2A1" until "."
    put it into card field "stimuli"
    close file "2A1"
  end if
  if cd fld "set" = "B" then
    open file "2B1"
    read from file "2B1" until "."
    put it into cd fld "stimuli"
    close file "2B1"
  end if
  if cd fld "set" = "C" then
    open file "2C1"
    read from file "2C1" until "."
    put it into card field "stimuli"
    close file "2C1"
  end if
  if cd fld "set" = "D" then
    open file "2D1"
    read from file "2D1" until "."
    put it into card field "stimuli"
    close file "2D1"
  end if
  if cd fld "set" = "E" then
    open file "2E1"
    read from file "2E1" until "."
```

```
    put it into card field "stimuli"
    close file "2E1"
   end if
  end if
  if cd fld "experiment" = 2 then
   if cd fld "set" = "A" then
    open file "2A2"
    read from file "2A2" until "."
    put it into card field "stimuli"
    close file "2A2"
   end if
   if cd fld "set" = "B" then
    open file "2B2"
    read from file "2B2" until "."
    put it into cd fld "stimuli"
    close file "2B2"
   end if
   if cd fld "set" = "C" then
    open file "2C2"
    read from file "2C2" until "."
    put it into card field "stimuli"
    close file "2C2"
   end if
   if cd fld "set" = "D" then
    open file "2D2"
    read from file "2D2" until "."
    put it into card field "stimuli"
    close file "2D2"
   end if
   if cd fld "set" = "E" then
    open file "2E2"
    read from file "2E2" until "."
    put it into card field "stimuli"
    close file "2E2"
   end if
  end if
  if cd fld "experiment" = 0 then
   if cd fld "set" = "P" then
    open file "2PP"
    read from file "2PP" until "."
    put it into card field "stimuli"
    close file "2PP"
   end if
  end if
  repeat until the number of lines in cd fld "random" = the number
   of lines in cd fld "stimuli"
   get the random of the number of lines in cd fld "stimuli"
   put it into trick
   put 1 into counter
   repeat forever
    if line trick of cd fld "stimuli" = line counter¬
    of cd fld "random" then
     set the cursor to Sad
     exit repeat
    end if
    if line trick of cd fld "stimuli" <> line counter¬
    of cd fld "random" then
     put counter + 1 into counter
```

```
      set the cursor to Happy
    end if
    if line counter of cd fld "random" = empty then
      put line trick of cd fld "stimuli" & return after cd fld
      "random"
      set the cursor to Happy
      exit repeat
    end if
   end repeat
  end repeat
  set the cursor to hand
  put "OK, I'm ready!" into cd fld "cross"
  show cd fld "cross"
  wait 100
  play "Crystal"
  put "Click on Begin Trial to start." into cd fld "cross"
  wait 200
  hide cd fld "cross"
end mouseUp
```

HyperTalk Script for the "Begin Trial" Routine.

```
on mouseUp
  hide menubar
  hide cd fld "cross"
  hide cd fld "stimuli"
  hide cd fld "random"
  hide cd button "Initiation"
  hide cd button "Begin Trial"
  hide cd button "Quit"
  hide cd button "Erase Sounds"
  hide cd button "Copy Sounds"
  hide cd button "Store Data"
  set cursor to none
  put "+" into cd fld "cross"
  put "winter" into cd fld "prime"
  put "dog" into cd fld "target"
  show cd fld "cross"
  wait 60
  hide cd fld "cross"
  show cd fld "prime"
  wait 15
  hide cd fld "prime"
  wait 15
  show cd fld "target"
  play "tone"
  wait 15
  hide cd fld "target"
  wait 100
  put "dream" into cd fld "prime"
  put "loaf" into cd fld "target"
  show cd fld "cross"
  wait 60
  hide cd fld "cross"
  show cd fld "prime"
  wait 15
```

```
hide cd fld "prime"
wait 15
show cd fld "target"
play "tone"
wait 15
hide cd fld "target"
wait 100
put "blank" into cd fld "prime"
put "candle" into cd fld "target"
show cd fld "cross"
wait 60
hide cd fld "cross"
show cd fld "prime"
wait 15
hide cd fld "prime"
wait 15
show cd fld "target"
play "tone"
wait 15
hide cd fld "target"
wait 100
put 0 into ace
repeat until ace = number of lines in cd fld "random"
 put ace + 1 into ace
 put "+" into cd fld "cross"
 put word 4 of line ace of cd fld "random" into cd fld "prime"
 put word 5 of line ace of cd fld "random" into cd fld "target"
 show cd fld "cross"
 wait 60
 hide cd fld "cross"
 show cd fld "prime"
 wait 15
 hide cd fld "prime"
 wait 15
 if word 3 of line ace of cd fld "random" < 6 then
  show cd fld "target"
  play "tone"
  wait 15
  hide cd fld "target"
  put cd fld "initials" && line ace of cd fld "random" ¬
  & return after card field "data"
 else
  show cd fld "target"
  play "tone"
  wait 15
  hide cd fld "target"
 end if
 wait 100
end repeat
set cursor to hand
show cd button "Initiation"
show cd button "Begin Trial"
show cd button "Quit"
show cd button "Erase Sounds"
show cd button "Copy Sounds"
show cd button "Store Data"
play "Crystal"
put "Thank You!" into cd fld "cross"
```

```
 show cd fld "cross"
 wait 200
 hide cd fld "cross"
end mouseUp
```