

2000

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THE ROLE OF PHONOLOGY IN ERROR RECOVERY

A Thesis Presented

by

JESSICA A. KEIR

Submitted to the Graduate School of the
University of Massachusetts Amherst in partial fulfillment
of the requirements for the degree of

MASTER OF SCIENCE

May 2000

Department of Psychology

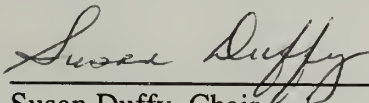
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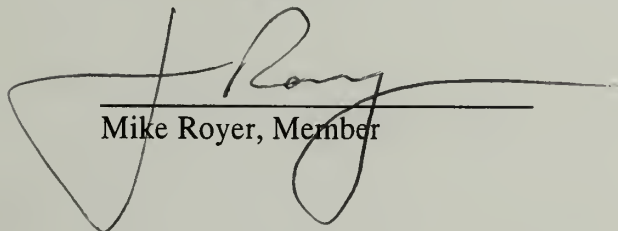
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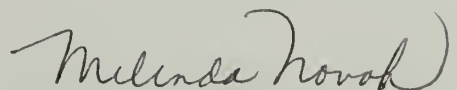
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ACKNOWLEDGMENTS

I would like to thank all the members of my committee for their time and helpful advice during the course of this project. I especially owe a great deal of thanks to my committee chair and advisor, Susan Duffy. Her tireless efforts were invaluable to the completion of this thesis. I would also like to thank Keith Rayner, not only for his advice and support, but also for the use of his lab and equipment, without which this work could not have been done. Finally I would like to thank Mike Royer for bringing a fresh perspective to the topic of ambiguous words.

In addition I need to thank my family, my friends, and the graduate students in my department. None of us would ever get anything done if we didn't help each other out. Special thanks go to Jeannine Bock for helping to keep me sane and to Brett Miller for spending hours reading and rereading stimuli with me.

ABSTRACT

THE ROLE OF PHONOLOGY IN ERROR RECOVERY

MAY 2000

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The role of a reader's short-term memory for a word's phonological code in recovering from errors in meaning selection during sentence comprehension was investigated. Readers were induced to make errors by presenting sentences in which biased ambiguous words were preceded by neutral context and later disambiguated toward their less frequent meaning (Duffy, Morris & Rayner, 1988). Reader's eye movements were monitored as they read. It is hypothesized that error recovery processes involve retrieving a short-term memory for an ambiguous word's pronunciation (phonological code) to re-access the word and select the intended meaning. If this is the case, recovery processes will be more difficult for heterophones (words with multiple meanings and pronunciations) than for homophones (multiple meaning and one pronunciation) because the reader initially selects the wrong pronunciation as well as the wrong meaning for the heterophones (Carpenter & Daneman, 1981, Folk & Morris, 1995). Whether the target word was in focus or not was manipulated by utilizing an it-cleft syntactic structure in the focused conditions. Birch and Garnsey (1995) suggested that focusing a word enhances memory for its phonological properties. If this is the case, then placing the ambiguous word in focus

could affect the error recovery process. Heterophone targets produced more processing difficulty than matched homophone targets, supporting the conclusion that phonology is involved in error recovery during sentence comprehension.

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CHAPTER 1

INTRODUCTION

Past research has shown that when a word is processed visually, not only is the word's semantic meaning accessed, but also its phonological code. Some of the earliest evidence for the use of phonology in reading was discovered when experimenters noted that even though words were being presented visually, participants were experiencing confusions that were based on phonology (Conrad, 1964; Wickelgren, 1965; Baddeley, 1966). For example, Conrad (1964) found that letter sets like BCPT and V, which all end with the same sound, were often confused with each other in recall, even when presented visually. A large number of further experiments have amounted to a great deal of evidence that phonology is activated in visual word recognition (Rubenstein, Lewis & Rubenstein, 1971; Meyer, Schvaneveldt, & Ruddy, 1974; Tanenhaus, Flanigan & Seidenberg, 1980; Perfetti, Bell & Delaney, 1988; Van Orden, Johnston & Hale, 1988; Pollatsek, Lesch, Morris & Rayner, 1992), and that when phonology is suppressed, comprehension suffers (Levy, 1975; Slowiaczek & Clifton, 1980; Baddeley, Eldridge & Lewis, 1981). For example, Slowiaczek and Clifton (1980) observed that when participants were required to block subvocalization by either counting or saying "colacolacola...", their ability to answer comprehension questions about the stories they read was impaired. They concluded that when subvocalization is suppressed, the memory representation of the text doesn't last as long (but see Besner, 1987 for a criticism of suppression techniques). This presupposes that suppressing the phonological code while reading does not result in an impoverished memory

representation in the first place. If phonology is a route through which meaning is accessed, then blocking subvocalization may lead to difficulty in retrieving the meaning of the words in the first place. Given this it would be the impoverished memory representation causing comprehension difficulty, not the fact that the memory representation is any less durable. But what exactly is the role of phonology? Does phonology strengthen memory for text, or could phonology actually be necessary to construct a full representation of a text in the first place? If activating a phonological code for each word is necessary for full comprehension, this leads to interesting predictions about what should happen if you lead a reader to choose a phonological code for a word that later turns out to be in error. I would like to suggest that phonology is not only involved in word identification, but is also used in subsequent error recovery processes. So, the question becomes how to trick readers into making an error in analysis in order to investigate whether phonology affects how they recover. One way in which this could be accomplished is through ambiguity.

Words can be ambiguous in meaning, such as palm(hand)/palm(tree), and this type of ambiguous word is called a homographic homophone. Other words, called homographic heterophones, are ambiguous both semantically and phonologically, such as tears(rips) /tears(crying). We will refer to the homographic homophones as homophones and the homographic heterophones as heterophones. Now, when a reader encounters an ambiguous word with no prior information to indicate which semantic meaning of the word is relevant, readers generally display frequency based effects: if one of the meanings of the word is much more frequently encountered in discourse (a

biased ambiguous word), readers assign the dominant meaning to the word and proceed. Which codes are activated and retained is relevant to what happens when subsequent information in the text indicates that the reader has the wrong meaning of the word. When this happens, readers must access some kind of representation of the word in order to recover from the misanalysis. When the word is a homophone, readers could presumably retrieve from working memory either the orthographic code or the phonological code of the word as a route to the correct meaning. However, with heterophones, there is not only a mismatch between the semantic meanings of the word, but also a mismatch between the phonological codes, so one potential route to the resolution of the ambiguous word is lost. If, as I suspect, the phonological code is used as part of the process of error recovery in homophones, but cannot be used to resolve heterophones, I expect to see differences in the patterns of reading for sentences containing these different types of words. An additional variable that could affect the recovery process is sentence focus. It appears that when elements of a sentence are in focus, the memory for the phonological code of these words is strengthened (Cutler & Fodor, 1979; Birch & Garnsey, 1995). Presumably, while this would help participants in the case of homophones, since a route to retrieval of the alternate semantic meaning is facilitated, it would actually impede the resolution of heterophones if the wrong phonological code is strengthened. There has been a great deal of previous research on ambiguity and focus that will be relevant to investigating the role phonology may play in error recovery.

As indicated above, one important factor in the resolution of ambiguous words is the frequency with which the various meanings occur in the language. Words like chest (body part/container), which have two meanings that occur with similar frequencies, behave differently from words like palm where one meaning is much more frequent than the other (in this case palm as part of a hand is more frequent than the plant meaning). Ambiguous words then, are often sub-classified into either balanced or biased ambiguous words, and each type shows different experimental effects. For example, with a neutral preceding context that does not favor either meaning, people spend longer looking at balanced ambiguous words than their controls, whereas no difference is found between biased ambiguous words and their controls (Rayner & Duffy 1986; Duffy, Morris & Rayner 1988). Rayner and Frazier (1989) found balanced ambiguous words were fixated longer than biased ambiguous words matched on length and frequency when the disambiguating material occurred after the target. These results have been interpreted as indicating that both meanings of balanced ambiguous words are activated when they are encountered in discourse, but when the target word is biased, the dominant meaning becomes available much earlier than the subordinate meaning, and is selected quickly.

A factor that influences the resolution of biased homophones is which meaning of the word is intended in the discourse. When the dominant (more frequent) meaning is intended, subjects show no difficulties in processing these words compared to control words matched in length and frequency (Duffy et al., 1988), and Rayner and Frazier (1989) found no difference between viewing times on the ambiguous word regardless of

whether the disambiguating information preceded or followed the target. These results indicate that the dominant meaning of a biased ambiguous word is quickly integrated when the word is encountered with neutral material or material supporting the dominant interpretation. However, when the subordinate meaning is intended, subjects often have difficulty in processing. Where the inflated processing occurs in homophones then depends on when the word is disambiguated and how strong the disambiguating context is. When the disambiguating information occurs before the ambiguous word is encountered, we observe inflated processing time on the ambiguous word when the subordinate meaning is intended compared to controls, (Duffy et al., 1988, Rayner, Pacht & Duffy 1994) and compared to when the dominant meaning is intended (Rayner & Frazier 1989); this effect has been termed the subordinate bias effect. On the other hand, when the disambiguating information occurs after the ambiguous word and is consistent with the subordinate meaning, we observe processing difficulty in the disambiguating region as compared to control sentences (Duffy et al 1988), and compared to when the disambiguation is to the dominant meaning (Rayner & Frazier 1989). These findings are attributed to the readers' need to activate the subordinate meaning of the word when the disambiguating information follows the target and biases towards the subordinate meaning of the word.

Some of the first work on heterophones was done by Carpenter and Daneman in 1981. They looked at heterophone targets in passages that contained early context that was consistent with one interpretation of the heterophones. After the target, a subsequent word either disambiguated the heterophone towards the same meaning as

the context or towards the other meaning. In an eye tracking study, they found that the time to read the disambiguating word, as well as time spent rereading both the disambiguating word and the target word were longer if the disambiguating information supported the second meaning. However, since the heterophones were not compared with other words these results speak only to the difficulty of resolving an ambiguous word when the meaning is switched after it is read. Daneman and Carpenter (1983) presented readers with passages that contained either a heterophone or a homophone target. They found that readers performed better on comprehension questions about homophone passages than heterophone passages. In a word by word reading task no reading time differences in the disambiguating phrase were significant, although the difference between the last word of the heterophone and homophone disambiguating phrases approached significance. They interpret the relative ease of resolving the homophone targets as compared to the heterophone targets to the availability of phonological information. However, these results do not indicate whether similar results would be found in passages that do not involve a context switch. In addition, they did not control for whether the ambiguous words were disambiguated towards their dominant or subordinate meaning, or for any differences in either that variable or overall degree of bias between homophones and heterophones.

Heterophones do tend to have one meaning that is more frequent than the other, and so are biased ambiguous words. These words, however, are ambiguous both in semantics and phonology, and they seem to show different patterns of results when compared to biased homophones. Folk and Morris (1995) used a neutral preceding

context, and did not find a difference between the time to read a biased homophone versus its matched control, replicating Rayner and Duffy (1986) and Duffy et al. (1988), but did find initial slowing on the encounter of heterophone targets as compared to their controls. If this result stands up to replication, it seems to indicate that with heterophones, readers are experiencing some form of competition between the multiple phonological codes when they are encountered. In addition, when subjects reached the disambiguating region after a heterophone, instead of showing increased processing time in that region as occurred with the homophones, processing difficulty took the form of a large number of regressions back to the target word. Folk and Morris attribute this difference to the particular difficulty of recovering the subordinate meaning of words with multiple phonological codes (when the reader has selected the wrong phonological code). The differences in the patterns in error recovery for homophones and heterophones appears to be good evidence for the fact that phonology is involved in the process of recovering from misanalysis. Homophones could be resolved in the disambiguating region by using the phonological code in the memory representation for the word. However, heterophones could not be resolved in the same way since the phonological code that readers accessed initially was not correct. In this case, readers had to look back to the original word in order to retrieve the correct meaning and phonological code. One must note here, however, that this result, although significant, is based on only four heterophonic target words, and only three of these actually showed the regression effect. If it is indeed the case that heterophones show a consistently

different pattern of error recovery than homophones, then this would be good evidence for the fact that phonological code plays a role in error recovery processes.

Another factor that we suspect may influence the resolution of these different types of ambiguous words is linguistic focus. Linguistic focus can be defined in quite a few different ways. In spoken discourse, focus is often indicated by stressing the intonation of the to-be-focused material (Bosch, 1988; Chafe, 1976; Hornby, 1974). Experimenters have also used questions before a discourse to focus part of the sentence (Cutler & Fodor 1979; Blutner & Sommer 1988; Birch & Rayner 1997), as in (1) from Cutler and Fodor 1979, where capitalization denotes the word(s) in focus.

1. Which man was wearing the hat?

The man ON THE CORNER was wearing the blue hat.

Other ways of manipulating focus in reading have been to use syntactic structure. Experimenters have used the indefinite this ("So, *this* MAN walks into a bar) (Gernsbacher & Shroyer, 1989; Gernsbacher & Jescheniak, 1995), there insertions (*There was* a STREET nearby) (Birch & Garnsey, 1995) and it-clefts (*It was* the SUBURB that received the most damage) (Bredart & Modolo, 1988; Birch & Garnsey, 1995; Birch & Rayner 1997). Many of these forms of focusing utilize unusual or non-typical sentence structures. For example, in (2) the word squirrel is focused because of its position in the it-cleft sentence.

2. *It was* the SQUIRREL *that* ate all the birdseed.

Focus in spoken language tends to aid processing, comprehension, and memory of the focused items. For example, Bock and Mazzella (1983) found when part of a

sentence is stressed by intonation, those sentences showed faster comprehension times than sentences without a focused element. Cutler and Fodor (1979) determined that the detection of a target phoneme was faster when the word in which the phoneme occurred was in focus. Gernsbacher and Shroyer (1989) observed that participants used focused concepts more often and more quickly when asked to finish an experimental narrative. Obviously, in written narrative, there are no intonational cues to focus, but effects of focus have been found using syntactic devices like those previously discussed.

When parts of discourse are focused in written text, it appears to increase the amount of time participants devote to processing that information, which leads to enriched memory for the focused concepts. Carpenter and Just (1977b), found better memory for focused concepts, presumably due to increased processing. They constructed texts with multiple referents for a subsequent pronoun. When one referent was syntactically focused (using a cleft or pseudo cleft construction), readers regressed twice as often to the focused referent than the non-focused referent when they encountered the pronoun. Bredart and Modolo (1988) determined that in sentences that contained errors like the Moses illusion, readers were more likely to detect the errors (it was Noah, not Moses) when they were in focus (3a) than when they were not (3b).

3a. It was *Moses* who took two animals of each kind on the Ark.

3b. It was two animals of each kind that *Moses* took on the Ark.

McKoon, Ratcliff, Ward and Sproat (1993) tested recognition for targets from short paragraphs and found that concepts that had more syntactic prominence showed increased accessibility from short-term memory during reading and in long-term

memory. In an on-line eye tracking experiment, Birch and Rayner (1997) found that target words that were in focus showed longer re-reading times than when the target word was not in focus. This result was due to the fact that readers made more regressions back to the target word when it was in focus than when it was not. However, the construction of the materials makes it difficult to determine whether focus is the critical factor. The materials were drawn from Birch and Garnsey (1995), and an example is given in (4) below.

4a. *There was this* **STREET** nearby that really worried the young mother.

4b. The traffic on the **street** nearby really worried the young mother.

(capitalization and italics added)

In the stimulus set, focused sentences like 4a only contain the focusing device prior to the target word. However, unfocused sentences like 4b consistently contain at least one content word before the target word occurs in the sentence. It is possible that this confound is responsible for the difference in the number of regressions to the target word instead of the focusing device itself. For example, it would not be unreasonable to assume that readers could simply have a tendency to regress more frequently to the first content word of a sentence, which would lead to refixations of street in 4a, but traffic in 4b. The confound in the stimuli also sheds doubt on the results from the speeded recognition task used by Birch and Garnsey (1995). Birch and Garnsey presented sentences like in 4 above, and found that target words were recognized as being from the sentence more quickly when in focus. However, the same confound that could be responsible for the difference in re-reading times in the Birch and Rayner experiment,

could also be responsible for the differences Birch and Garnsey found in recognition times for the target words. Stimulus problems aside, Birch and Garnsey looked not only at what happens to recognition memory for words dependent on focus, but also investigated whether focus affects the way phonological information is retained.

Birch and Garnsey (1995) tested recognition times for phonological neighbors of target words. An example is given in (5) below.

5a. *It was* some **MUSTARD** that had caused them to develop food poisoning.

5b. Dave brought pickles, **mustard**, and hot dog buns for tonight's cookout.

Target word: Medic (Italics and capitalization added)

Note that the correct answer would be no for all phonological targets. They observed that in a delayed memory task, participants had significantly more trouble recognizing that a phonological neighbor was not in the text when the target word was in focus than when the target word was not in focus, and interpreted this result as suggesting that focusing a word enhances memory for its phonological properties. Again, this conclusion is also based on confounded stimuli, so bears replication.

CHAPTER 2

EXPERIMENT 1

The current experiment investigated how the phonological code of a word is used in the resolution of biased ambiguous words. Two factors were varied: the strength of the phonological code, which was mediated by whether the target was in focus or not, and whether the phonological code was correct for both meanings of the target (homophones), or was incorrect for the subordinate meaning of the target (heterophones). Participants read sentences containing three types of words: biased homographic heterophones, biased homographic homophones, and neutral control words that were all matched on length and frequency. Sentences either contained an it-cleft construction and put the target word in focus, or did not. The control words were not ambiguous at all, the homophones were ambiguous semantically, and the heterophones were ambiguous both semantically and phonologically. The disambiguating information for the ambiguous words always followed the target word. We expect that we should be able to ascertain how the different types of ambiguity affect resolution of the words and how these results change depending on focus. An example of the stimuli is given below in table one.

Predictions

In the case of the biased homophones, no first pass differences were expected between the control words and the target words (Rayner & Duffy, 1986; Duffy, Morris & Rayner, 1988). When participants reach the disambiguating region, if they are holding onto the dominant (and wrong) meaning of the target word, they must perform

Table 1. Sample Item

I. Sentence frame set 1

a.) Heterophonic Homograph/Focus

That autumn day, it was the **sewer** that was threading her needle that was burned in the fire.

b.) Heterophonic Homograph/No Focus

That autumn day, the **sewer** that was threading her needle was burned in the fire.

c.) Homophonic Homograph/Focus

That autumn day, it was the **slide** that was stuck in the projector that was burned in the fire.

d.) Homophonic Homograph/No Focus

That autumn day, the **slide** that was stuck in the projector burned in the fire.

e.) Control/Focus

That autumn day, it was the **grove** that was hidden in the forest that was burned in the fire.

f.) Control/No Focus

That autumn day, the **grove** that was hidden in the forest was burned in the fire.

II. Sentence frame set 2

On Tuesday, it was the **sewer** we discovered threading her needle that made us curious.

On Tuesday, the **sewer** we discovered threading her needle made us curious.

On Tuesday, it was the **slide** we discovered stuck in the projector that made us curious.

On Tuesday, the **slide** we discovered stuck in the projector made us curious.

On Tuesday, it was the **grove** we discovered hidden in the forest that made us curious.

On Tuesday, the **grove** we discovered hidden in the forest made us curious.

III. Sentence frame set 3

Wandering around, it was the **sewer** that I found threading her needle that really made my day.

Wandering around, the **sewer** that I found threading her needle really made my day.

Wandering around, it was the **slide** that I found stuck in the projector that really made my day.

Wandering around, the **slide** that I found stuck in the projector really made my day.

Wandering around, it was the **grove** that I found hidden in the forest that really made my day.

Wandering around, the **grove** that I found hidden in the forest really made my day.

some kind of reanalysis. This could be done either by using the orthographic or phonological code to retrieve the other meaning while in the disambiguating region, or participants could regress to the target word. Previous studies have found that with homophones, participants are able to resolve the ambiguity without the need to regress

to the target. Thus we expected that, when the target was not in focus, subjects would show inflated processing time in the disambiguating region as compared to control words as they used either phonology or orthography to resolve the target word to its subordinate meaning (Dopkins, Morris, & Rayner, 1992).

When the biased homophones were in focus, we still expected to observe an inflated processing time effect in the disambiguating region, but we believed that it would be smaller than the no-focus condition. If focus does indeed help the reader to hold onto the phonology of the word, then in the focused condition it should help readers to recover the subordinate meaning. If the Birch and Rayner effect of more regressions to any target word when it is in focus as compared to when it is not replicates, we expected to see this effect in not only the focused homophone condition, but in all of the focused conditions.

With the heterophones, we expected that first pass reading times on the target words would be longer than both the normal and the homophone targets in both the focus and the non-focused conditions if we replicated Folk and Morris (1995). This would indicate that the multiple phonological codes are competing when the word is encountered. If the effect is not found, this may be due to the small number of items in the Folk and Morris (1995) study. We actually expected that in the disambiguating region, time spent fixating in the region would be more similar to the normal conditions than to the homophone conditions if our results paralleled Folk and Morris (1995). The main effect we expected to see once the heterophone disambiguating region was reached was a large number of regressions to the target word, especially in the focused

condition. The rationale is that, in contrast to the homophone condition, readers have both the incorrect meaning and the incorrect phonological code. With the homophones, phonology can be used to retrieve the correct meaning of the word in the disambiguating region. However, when the disambiguating region is encountered in the heterophonic condition, the route to error recovery through phonology is not available since the wrong phonological code has been selected. Because of this we expected to see a large increase in the number of regressions readers made back to the target word over both the normal and the homophonic conditions. This pattern was expected for both focused and non focused heterophones, but was predicted to be even more extreme in the focused condition. If focus enables the reader to retain the phonological code of the target word better, but they are holding onto the wrong phonological code, this could cause more competition between the dominant and subordinate meanings of the word while readers attempt to correct the initial error in analysis. This could either be shown in more regressions, or longer durations of the regressions back to the target word.

Method

Participants

58 members of the University of Massachusetts community were paid or received experimental credit for participation in the study. The participants were all native English speakers. The data from 18 subjects could not be used because of either an inability to accurately track where their eyes were fixated, or because they had numerous track losses that rendered their data impossible to analyze. An additional 4 subjects' data was not utilized in order to have an equal number of subjects in each

counterbalancing condition; these subjects were randomly selected from the conditions with extra subjects in them.

Apparatus

Eye movements were recorded by a Stanford Research Institute Dual Purkinje eye tracker which has a resolution of less than 10' of arc. The eye tracker was interfaced with an American Computer Innovations 486 computer which ran the experiment. Viewing was binocular, with eye location recorded from the right eye. The position of the participant's eye was sampled every millisecond by the computer and averaged over four consecutive samples. The averaged horizontal and vertical positions of the eye were compared with those of the previous sample to determine whether the eye was fixated or moving.

Sentences were presented on a NEC MultiSync monitor, with up to 80 character spaces per line. During the experiment, the participant was seated 62 cm. from the monitor, where four characters equal one degree of visual angle. The characters were presented in lower case except for the first letter of words at the beginning of a sentence and proper names. The room that the experiment took place in was dark except for an indirect light source that enabled the experimenter to keep notes during the experiment. The light source was adjusted to a comfortable level for each participant.

Materials

Two hundred and sixteen experimental sentences were constructed. Each sentence was two or three lines long. The target word never appeared at the very beginning or end of a line. The experimental sentences were based on twelve item

triples. Each item triple was based on a heterophonic homograph, a homophonic homograph, and a control word that were all matched on length and frequency. The average lengths of the target words were 5.8 characters for the heterophones (range = 4-10), 5.4 for the homophones (range = 4-11) and 5.8 for the controls (range = 4-10). The mean frequencies were calculated utilizing Francis and Kucera's (1982) norms. The mean frequency of the heterophones was 22 (range = 2-57), the mean frequency of the homophones was 20 (range = 1-56), and the mean frequency of the controls was 24 (range = 3-56). For each group of target words, three sets of sentence frames were generated. In each set, there were three frames, one for each target word. It was important that the sentence frames in each set were exactly the same for all three targets before the target word, and that the disambiguating region both was separated from the target word by at least one word, and was as similar as possible in length and form across the three targets. Overall, we tried to make the frames within each set as similar as possible, with the constraint that the disambiguating region had to differ in order to disambiguate the ambiguous homophone or heterophone to its subordinate meaning. In addition, the sentence frames had to be dissimilar enough across sets that subjects would not be aware that they belonged to the same overall item. Six conditions were created by generating a focused and non-focused version of every sentence. An example of an item triple is presented in Table 1.

Norming

Two norming studies were run in order to assess the materials. First of all, in order to determine the relative meaning frequencies of the target words in this population of participants, students at the University of Massachusetts were presented with the target words in isolation and asked to write down the first word that came to mind that was related to the target word, and then to use the target word in a sentence. This enabled us to determine whether the heterophones and homophones that we paired for the experimental items were equally biased. The results were that the heterophones were completed with the dominant meaning 76% of the time and the subordinate meaning 19.2% of the time and the homophones were completed with the dominant meaning 77% of the time and the subordinate meaning 18.3% of the time. In addition a norming study was run to determine whether the disambiguating regions were equally good at disambiguating the words. Participants read the sentences, then circled which meaning of the word was intended in that sentence. Then participants were asked to rate the disambiguating regions for how well they enabled them to get to the subordinate meaning of the target words. The rating results on a scale from 1 (not at all helpful in getting the intended meaning) to 5 (very helpful in getting the intended meaning) were 4.2 for heterophones and 4.3 for homophones. Participants made an average of 1 error in identifying the intended meaning for the heterophone targets and an average of .5 errors identifying the intended meaning for the homophone targets (each participant rated 24 disambiguating regions, 12 each in heterophone and homophone conditions). When participants made an error their rating of the disambiguating information was not

utilized. These norming tasks enabled us to be certain that our words were indeed matched biased ambiguous words, that they were disambiguated, and that our disambiguations were equally good for heterophones and homophones.

Design

Each participant read 36 experimental sentences, six in each of the six conditions created by crossing type of target (heterophone, homophone or neutral control) and focus (focus or no focus). Each participant was randomly assigned to one of six counterbalancing sets of sentences. For example, a given participant would have read three of the sentences presented in Table 1, one each of the heterophone, homophone, and control sentences. Each set of 36 experimental sentences appeared in a larger set of 104 sentences. One fourth of the sentences were followed by a comprehension question. Comprehension questions were all yes/no questions.

Procedure

When a participant arrived for the experiment, a bite bar was prepared to eliminate head movements, and the eye-tracker was calibrated. The initial calibration procedure took approximately five minutes. Participants were told to read normally, and that they should be prepared to answer comprehension questions. Before every sentence, a series of boxes appeared on the computer screen. Participants were instructed to look at the center box, then at a series of boxes until they reached the uppermost left hand box, which is where the first word of the next sentence appeared. The eye-tracker's calibration was verified between every trial by making sure that when the participant fixated each box, the computer indicated that location as well. Each

participant read 6 practice sentences followed by the set of 104 sentences (36 experimental and 68 filler). Participants were told to end each trial by pressing a button when they felt they had comprehended each sentence. One fourth of the time a comprehension question followed the sentence, and participants responded to the questions by pressing either the left or the right hand button on a pad to indicate a Yes or No answer. Participants were quite accurate in answering the comprehension questions (91% correct).

Results and Discussion

Fixation durations on the following regions of the sentences were examined: the beginning of the sentence region, the target region consisting of the target word (heterophone, homophone or control), the post-target region which consisted of the next 1 to 2 words, the pre-disambiguating region which consisted of the subsequent 1 to 2 words, and the disambiguating region. Additional regions that were analyzed will be discussed in the body of this section. The primary measures are first fixation, first pass, gopast, percent regressions and second pass. First fixation is the duration of the first fixation made in a given region. First pass time is the sum of all fixation durations from the first fixation within a region to the last fixation before leaving the region in any direction. For a single word, this measure is also frequently called gaze duration. Gopast time is the sum of all fixations beginning with the first fixation in the region and ending with the last fixation before going forward to fixate a later position in the sentence. This measure includes the first pass fixations in the region plus any regressions made from the region to previous regions, and any refixations of that region

before leaving it to the right. Thus it is a measure of how much processing the reader carried out to comprehend the region well enough to move beyond it. Percent regressions out of a region is the percentage of trials where one or more first pass fixations in a region were followed by a fixation in an earlier part of the sentence. Percent regressions into a region is the percentage of trials where one or more fixations in a region were preceded by a fixation in a later region of the sentence. The second pass measure is a sum of the durations of all the refixations of a region after a reader has left the region. Second pass can either include only refixations after a reader has left in a forward going direction (to the right), or can include refixations after leaving the region both to the left and the right.

Fixation durations of less than 80ms or greater than 800ms were excluded from the analysis. In cases where readers make very short fixations on a word, it is highly likely that much of the processing associated with that word was done on the prior fixation (Morrison, 1984). When readers make very long fixations, they are very likely to be track losses (Rayner & Pollatsek, 1987). For the main effects analyses, 3 X 2 ANOVAs were conducted with ambiguity (heterophone vs. homophone vs. control) and focus (focused vs. no focus) as within-subjects factors. When main ambiguity effects were significant, 2X2 ANOVAs were performed with ambiguity and focus as within-subjects factors. F1 analyses are the subject analyses, F2 analyses are the items analyses. All effects reported are significant at the .05 level unless otherwise noted. At the outset it should be noted that while the focus manipulation did exhibit a suggestive pattern of results in some measures, there were no significant interactions with the level

of ambiguity of the target. It may be that the focusing device that was used in the current experiment was not strong enough to affect the resolution process. In addition there were no main effects of focus that were not potentially explainable by differences in length between focused and non-focused conditions. As a result, the remainder of this section will address effects of ambiguity, and effects of focus will not be further discussed.

Ambiguity Results

Table 2 contains first fixation, first pass, and gopast times for the target word and the post-target region immediately following the target word. Within the analyses of the target word region no effects were significant. Unlike Folk and Morris (1995), evidence of an immediate slowdown on the target word itself was not found in the heterophone conditions.¹

In the first fixation data in the post-target region there was a main effect of ambiguity, $F_1(2,70) = 4.85$, $MSe = 2,561$, $F_2(2,70) = 5.05$, $MSe = 3,303$.² Further analysis indicated that this effect was due to an inflation of the homophone conditions over the control conditions, $F_1(1,35) = 11.95$, $MSe = 2,059$, $F_2(1,35) = 9.69$, $MSe = 3,028$. This result was surprising because previous literature indicates that readers should not experience difficulty with biased homophones until they receive information inconsistent with the dominant meaning. However, analysis of the norming association task indicated that participants completed the homophones with the dominant meaning 77% of the time (heterophones were completed with the dominant meaning 76% of the time). Previous studies have used more biased words. In Duffy, Morris and Rayner

Table 2. Mean First Fixation, First Pass and Go Past Times for the Target and Post-Target Regions

Target Region

	Heterophones	Homophones	Controls	
First Fixation				
Focused	277ms	269ms	273ms	(273ms)
No Focus	270ms	273ms	273ms	(272ms)
	(274ms)	(271ms)	(273ms)	
Gaze Duration				
Focused	322ms	298ms	315ms	(312ms)
No Focus	336ms	321ms	325ms	(327ms)
	(329ms)	(310ms)	(320ms)	
Go Past				
Focused	405ms	419ms	425ms	(416ms)
No Focus	440ms	393ms	412ms	(415ms)
	(423ms)	(406ms)	(419ms)	

Post-Target Region

	Heterophones	Homophones	Controls	
First Fixation				
Focused	259ms	265ms	243ms	(256ms)
No Focus	248ms	274ms	243ms	(255ms)
	(254ms)	(270ms)	(243ms)	
Gaze Duration				
Focused	316ms	329ms	295ms	(313ms)
No Focus	281ms	326ms	272ms	(293ms)
	(299ms)	(328ms)	(284ms)	
Go Past				
Focused	515ms	417ms	395ms	(442ms)
No Focus	428ms	398ms	369ms	(298ms)
	(472ms)	(408ms)	(382ms)	

(1988), norming results indicated that participants used the dominant meaning 93% of the time for biased words, and 57% of the time for unbiased words. Frazier and Rayner (1989) used words from the same set as Duffy et al., and their completion results were 92% and 57%. This puts the current set of homophones between biased stimulus sets and unbiased sets that have been previously utilized. It may well be that moderately biased homophones like the ones in the current experimental set experience competition from the subordinate meaning occurring downstream from the target (in this case first fixation and first pass effects in the post-target region).

The results indicate that the heterophone conditions also reveal difficulty in processing before the disambiguating information is reached. Specifically a main effect of ambiguity was observed in the go past measure in the post-target region, $F_1(2,70) = 4.85$, $MSe = 31,376$, $F_2(2,70) = 5.09$, $MSe = 42,626$ (see table 2). Further analysis indicated that readers spent more time before moving past this region in the heterophone conditions than the homophone conditions, $F_1(1,35) = 4.13$, $MSe = 35,883$, $F_2(1,35) = 4.42$, $MSe = 47,746$, and more time in the heterophone conditions than the control conditions, $F_1(1,35) = 6.91$, $MSe = 41,348$, $F_2(1,35) = 8.40$, $MSe = 48,549$. Additionally, as shown in table 3, a main effect of ambiguity was observed in the go past measure in the pre-disambiguation region (after the post-target region but before the disambiguating region), $F_1(2,70) = 11.32$, $MSe = 20,672$, $F_2(2,70) = 5.69$, $MSe = 64,844$. Further analysis indicated that heterophone conditions produced longer times than both homophone conditions, $F_1(1,35) = 7.27$, $MSe = 28,210$, $F_2(1,35) = 4.43$, $MSe =$

Table 3. Mean Go Past Times for the Pre-Disambiguation Region

Pre-Disambiguation Region

	Heterophones	Homophones	Controls	
Go Past				
Focused	533ms	466ms	424ms	(474ms)
No Focus	535ms	451ms	420ms	(469ms)
	(534ms)	(459ms)	(422ms)	

= 93,595, and control conditions, $F_1(1,35) = 18.97$, $MSe = 23710$, $F_2(1, 35) = 8.64$, $MSe = 76,820$.

These results indicate that heterophone targets also led to difficulty in processing before the disambiguating information was encountered. The pattern, however, is different than in the homophone conditions. Whereas the moderately biased homophones produced an inflation of first fixation times (which also led to a significant inflation of first pass times) in the post-target region, heterophones exhibited difficulty in go past measures on both the post-target region and the pre-disambiguating region. This means that in the heterophone conditions readers were spending more time regressing to earlier regions before proceeding forward. Given that the inflation observed in the heterophone conditions consists of regression effects, this is evidence that unlike in the homophone conditions, readers are already trying to initiate a form of error recovery by rereading earlier parts of the sentence. Readers may not be experiencing competition from the subordinate meaning as in the homophone conditions, but instead be experiencing competition from the secondary sound code

leading to a 'checking effect', where they are slightly unsure what it is that they just read, and so they look back before continuing with the sentence.

Table 4 contains the first pass times and gopast times for the disambiguating region. In the first pass measure there was a main effect of ambiguity $F_{1(2,70)} = 9.09$, $MSe = 17,779$, $F_{2(2,70)} = 4.56$, $MSe = 35058$. Further analysis indicated that this effect was due to the inflation of heterophone conditions over both homophones, $F_{1(1,35)} = 18.23$, $MSe = 15,969$, $F_{2(1,35)} = 10.83$, $MSe = 27,597$, and controls (marginal by items), $F_{1(1, 35)} = 9.26$, $MSe = 19.470$, $F_{2(1,35)} = 3.88$, $MSe = 41,063$, $p = .06$. Although we had expected to find them, first pass effects were not observed in the disambiguating region in the homophone conditions. However, in Duffy, Morris and Rayner (1988), the measure that showed inflation for homophones over controls was actually a gopast measure on the disambiguating region, a region which in their study extended to the end of the sentence. The next table presents data that show homophone effects in regressions out of that region and time spent outside that region before finishing the sentence. Another possibility for the lack of a homophone result in this measure is that our disambiguating material may be weaker than those used in previous studies, and that in the homophone conditions where a subordinate sound code has not already caused readers trouble, that readers are taking longer to notice that the disambiguating information is inconsistent with the meaning of the homophone.

In the gopast times on the disambiguating region a main effect of ambiguity was observed, $F_{1(2,70)} = 21.62$, $MSe = 50,878$, $F_{2(2,70)} = 13.99$, $MSe = 85,101$. Further

Table 4. Mean First Pass and Go Past Times for the Disambiguating Region

Disambiguating Region

	Heterophones	Homophones	Controls	
First Pass				
Focused	762ms	660ms	709ms	(710ms)
No Focus	750ms	672ms	661ms	(694ms)
	(756ms)	(666ms)	(685ms)	
Go Past				
Focused	1165ms	886ms	922ms	(991ms)
No Focus	1088ms	972ms	876ms	(979ms)
	(1127ms)	(929ms)	(899ms)	

analysis indicated that this was due to heterophone times being inflated over both the homophone conditions, $F_1(1,35) = 23.74$, $MSe = 59,143$, $F_2(1,35) = 17.14$, $MSe = 93,187$, and the control conditions, $F_1(1,35) = 28.45$, $MSe = 65,509$, $F_2(1,35) = 18.91$, $MSe = 103,515$. The main ambiguity effects are consistent with the first pass effects; heterophones generate more difficulty than homophones and controls in the time from when the disambiguating material is encountered until readers feel ready to move on further into the sentence.

In order to be consistent with Duffy, Morris and Rayner (1988), a region comparable to their disambiguating region was constructed by collapsing the disambiguating region with the end of the sentence region, so that one could observe whether homophone difficulty emerges in measures that contain not only the disambiguating material, but all the subsequent material until the end of the sentence. With these stimuli this information was equivalent across all six conditions. This new

region will be referred to as the expanded disambiguating region. Although homophone results in the smaller disambiguating region were expected, instead of in a measure which includes the information through the end of the sentence, it would be consistent with Duffy et. al. if I find the results anywhere from the disambiguating region until the end of the sentence. Homophone effects did indeed emerge in analysis of the expanded disambiguating region.^{3 & 4}

Table 5 shows the percent regressions out of this region back to earlier portions of the sentence and the time spent outside of this region (in regressions) before moving past it (essentially this is a gopast measure, but it only includes the regressions, not reading time in the actual region). In the percent regressions out of the expanded disambiguating region there was a main effect of ambiguity, $F_1(2,70) = 17.25$, $MSe = 382$, $F_2(2,70) = 12.72$, $MSe = 433$. Further analysis indicated that all three levels of ambiguity were significantly different from each other, with heterophones inflated over homophones, $F_1(1,35) = 8.28$, $MSe = 527$, $F_2(1,35) = 7.70$, $MSe = 406$, heterophones inflated over controls, $F_1(1,35) = 45.57$, $MSe = 287$, $F_2(1,35) = 21.69$, $MSe = 507$, and homophones inflated over controls, $F_1(1,35) = 7.02$, $MSe = 332$, $F_2(1,35) = 6.21$, $MSe = 385$. The corresponding time spent in regressions before finishing the sentence (see table 5), also exhibited a main effect of ambiguity, $F_1(2,70) = 29.24$, $MSe = 109,804$, $F_2(2,70) = 18.29$, $MSe = 153,391$. Further analysis indicated that all three levels of ambiguity were significantly different from each other with heterophones inflated over homophones, $F_1(1,35) = 20.66$, $MSe = 166,236$, $F_2(1,35) = 14.73$, $MSe = 200,230$, heterophones inflated over controls, $F_1(1,35) = 50.45$, $MSe = 116,402$, $F_2(1,35) = 27.67$,

Table 5. Mean percent regressions out of the disambiguation region and time spent outside of the expanded disambiguation region before going past it

Expanded Disambiguation Region

	Heterophones	Homophones	Controls	
Regressions Out				
Focused	57%	43%	37%	(46%)
No Focus	52%	44%	34%	(43%)
	(55%)	(44%)	(36%)	
Time Spent Outside the Disambiguation Region Before Going Past it				
Focused	788ms	369ms	287ms	(481ms)
No Focus	618ms	419ms	311ms	(449ms)
	(703ms)	(394ms)	(299ms)	

MSe = 186,440, and homophones inflated over controls, $F_1(1,35) = 6.95$, MSe = 46,775, $F_2(1,35) = 4.17$, MSe = 73,502.

Since participants were regressing frequently, second pass times in the sentences were analyzed. What was of interest was rereading of relevant information given that the participant had already read the disambiguating information. However, since regressions out of regions earlier than the disambiguating region were observed (the post-target and pre-disambiguation region gopast results for the heterophones) second pass times on the target word alone would be compromised because they would include regressions made back to it from any subsequent region in the sentence. In order to avoid this problem, the target, post-target and pre-disambiguation regions were collapsed into one expanded target region and percent regression into and re-reading time for the new region were assessed. Any regressions to the expanded target region

have to come from the disambiguating region or later, and so are a measure of rereading after readers have encountered the disambiguating information.

Table 6. Mean percent regressions into and second pass times for the expanded target region

Expanded Target Region

	Heterophones	Homophones	Controls	
Regressions In				
Focused	46%	34%	28%	(36%)
No Focus	40%	38%	20%	(33%)
	(43%)	(36%)	(24%)	
Second Pass Times				
Focused	407ms	188ms	136ms	(244ms)
No Focus	357ms	250ms	166ms	(258ms)
	(382ms)	(219ms)	(151ms)	

Table 6 contains percent regressions into and second pass times for the expanded target region. The results for percent regressions into the target region exhibited a main effect of ambiguity, $F_1(2,70) = 15.76$, $MSe = 371$, $F_2(2,70) = 19.36$, $MSe = 294$. Further analysis indicated that the percent regressions differed across all levels of ambiguity, with heterophones exhibiting more regressions than homophones (marginal by subjects), $F_1(1,35) = 3.53$, $MSe = 451$, $p = .07$, $F_2(1,35) = 4.62$, $MSe = 286$, heterophones displaying more regressions than controls, $F_1(1,35) = 25.72$, $MSe = 445$, $F_2(1,35) = 35.34$, $MSe = 312$, and homophones showing more regressions than controls, $F_1(1,35) = 20.80$, $MSe = 216$, $F_2(1,35) = 16.64$, $MSe = 283$.

Second pass times in the expanded target region show the same pattern. The main effect of ambiguity is significant, $F_1(2,70) = 29.73$, $MSe = 33,933$, $F_2(2,70) = 18.38$, $MSe = 52,701$. Heterophone conditions caused longer rereading times in the expanded target region than homophone conditions, $F_1(1,35) = 19.85$, $MSe = 47,880$, $F_2(1,35) = 12.88$, $MSe = 69,729$, heterophones were inflated over controls, $F_1(1,35) = 49.85$, $MSe = 38,319$, $F_2(1,35) = 28.18$, $MSe = 65,316$, and homophones were also inflated over controls, $F_1(1,35) = 10.62$, $MSe = 15,600$, $F_2(1,35) = 7.25$, $MSe = 23,060$.⁵

The ambiguity results display clear differences between conditions with heterophone and homophone targets. In the post-target region, processing difficulty in homophone conditions as compared to control conditions was observed in first fixation times (also leading to a significant inflation of first pass times). This result is consistent with previous results for unbiased words, although it occurs one region later, instead of on the target word itself. Thus the data contains evidence that moderately biased homophones may sometimes behave more like unbiased words than biased words. The inflation of first fixation reading times indicates that readers experienced competition due to activation of the subordinate meaning for the moderately biased homophones. Heterophones also displayed difficulty before the disambiguating region was reached. They produced longer go past times in the post-target region and pre-disambiguating region, but did not show the first fixation effect like the homophones. Presumably this difference is due to the fact that heterophones not only have multiple meanings, but also multiple sound codes. Competition from a second sound code may result in this pattern

of regressions. It suggests that readers may be performing a type of error recovery before they even know that they have made an error. More specifically, competition from the subordinate sound code may lead readers to be unsure as to what they have actually read, resulting in a 'checking effect', where they look back frequently before continuing forward in the sentence.

Two disambiguating regions were analyzed: a fairly specific disambiguation region, and the expanded disambiguating region that included all information until the end of the sentence. In the specific disambiguating region first pass and go past effects were observed for heterophones only (go past effects for heterophones were also observed in the expanded disambiguating region). This indicates that the heterophones were much more difficult than either the homophones or controls when reading time within the specific disambiguation region is assessed. In analyses of the expanded disambiguating region homophone effects emerged in measures that assess percent regressions out to earlier points in the sentence and rereading times for earlier information in the sentence before finishing the region. Although the earlier inflation of first fixation times in the post-target region is suggestive that the secondary meaning of the homophones was sometimes activated before the disambiguating information was read, later homophone measures still exhibit difficulty when compared to controls. In both regressions out of the expanded disambiguating region, and time spent reading earlier regions of the sentence before finishing the expanded disambiguating region, all three levels of ambiguity differed from each other, with heterophone conditions leading to the most regressions out and the longest reading times, followed by homophone

conditions and finally control conditions. This pattern is consistent with the levels of ambiguity amongst the three conditions; heterophones, which have two sound codes and two meanings are the most difficult, homophones, which only have two meanings, are intermediate, and the control conditions display the least difficulty.

Regressions into and second pass times on the expanded target region also reflected the same pattern: heterophone conditions displayed the most regressions into and longest second pass times on the region, followed by homophones, and finally by control conditions. These results indicate that when a reader has not only the wrong meaning for a word, but also the wrong sound code, that error recovery becomes much more difficult than when only the wrong meaning is accessed.

CHAPTER 3

GENERAL DISCUSSION

The results of the experiment presented in this paper provide evidence that phonology is important to the processes of error recovery in reading. Whether phonology is active in error recovery was investigated by utilizing a unique set of words in English called heterophones. The orthography of these words is linked to not only multiple meanings, but also multiple sound codes. Therefore by inducing readers to take the wrong meaning of these words by providing information that disambiguates to the subordinate meaning of the word late in the sentence, we have induced them to initially activate the dominant(wrong) sound code of the word. Heterophone conditions were compared to both homophone conditions (sentences with targets that were only ambiguous in meaning) and control conditions (sentences with unambiguous targets). We also attempted to investigate whether using a focusing device on the target word (an it-cleft construction) interacted with the way the ambiguity was resolved.

What are the implications of the initial heterophone results? The pattern of results for the initial encounter of heterophone targets suggests that there may be competition from the subordinate sound code. This does not necessarily mean that the phonological code was initially used to access the meaning of the heterophones, but it does indicate that somewhere in the access process both codes are activated. Although inflated times on the target word itself were not found as in Folk and Morris (1995), heterophones were slowed over both homophones and controls in the time to go past the two regions following the target word (preceding the disambiguating information). The

significant go past results are due to the fact that readers more often looked back to previous regions in the sentence before they even reached the information that informed them that they had the wrong meaning of the word. Given this, it is hypothesized that competition from the subordinate sound code may lead to a 'checking effect', where readers are unsure as to what they have just read and reread previous information before moving along further into the sentence.

Since the evidence indicates that after heterophones are encountered both sound codes are accessed it would be interesting to examine whether this would also occur if the disambiguating information precedes the heterophones. I strongly suspect that if the information disambiguates the word towards the subordinate meaning that readers will still experience competition from the dominant sound code. Although it would be beneficial to readers to suppress the dominant sound code, I suspect that this will prove impossible. If this type of resolution is compared for homophones and heterophones both should exhibit a subordinate bias effect (slowdown on the ambiguous targets), but if the dominant sound code is also competing, then I expect that heterophone conditions will exhibit additional slowdown either at the target or very shortly thereafter. Another interesting case would be to examine whether readers would still show competition effects from the second sound code if the sentence context supports the dominant sound code. If readers experienced competition similar to that seen in our experiment both when they had initial information supporting the subordinate code and when the information supports the dominant sound code (as compared to homophone conditions)

it would be excellent evidence that sound codes are exhaustively accessed regardless of context.

What are the implications of the heterophone effects that occur when readers encounter disambiguating information that supports the subordinate meaning? After the disambiguating information is encountered, the pattern of results for the heterophone conditions strongly suggests that having the incorrect sound code is highly detrimental to resolving the sentence towards the subordinate meaning of the target. Although initial heterophone effects were limited to regression measures, once the disambiguating material was encountered heterophone conditions also exhibited first pass effects. Heterophone conditions led to longer times to read the disambiguating information, and to go past the disambiguating information to later regions of the sentence. In addition heterophone conditions also led to the highest percentage of regressions back into the target region, and the longest second pass times on the target region. Since the only difference between the heterophone and homophone conditions should be the fact that the heterophones have multiple sound codes, the differences in the reading patterns in the heterophone and homophone conditions is good evidence that having the incorrect sound code for an ambiguous word makes it very difficult for readers to recover the subordinate meaning even after disambiguating material is encountered.

Why is it harder to resolve a target towards its subordinate meaning when the target is a heterophone than a homophone? There are multiple explanations for this pattern of data. It could be that phonological information is still available to readers as they reach the disambiguating material, and it is used in error recovery processes. Since

this information is incorrect in the heterophone conditions it cannot be used to facilitate recovery of the subordinate meaning, but could be used to facilitate recovery for the homophone conditions, leading to greater difficulty in heterophone conditions. If this explanation is correct, it would be informative to examine the time course of the activation of this phonological information. This theory makes the interesting prediction that if the sound code for a word is used in error recovery, and if we assume that the phonological code is held in a memory that will eventually decay, that the resolution of homophones could become more difficult if the time to get to the disambiguating material exceeds the time that the phonological code hangs around (if phonological information is helping for homophones). On the other hand in the heterophone conditions if readers are attempting to use the wrong phonological information to resolve the sentence, then the decay of the wrong information should not make heterophones any harder to resolve.

Of course the reasoning above is dependent on the stipulation that there is some kind of memory for the phonological code of a word. It is certainly also possible that the phonological information is not available in either the heterophone or homophone conditions. If this is the case then the differences in processing difficulty could be because when readers attempt to recover the subordinate meaning of the heterophones through either a memory for the orthography or by looking back at the target word, that they cannot avoid reaccessing the dominant sound code. If in the heterophone conditions readers experience competition from the dominant sound code when attempting error recovery (obviously this cannot happen for the homophones since there

is only one sound code and it is correct for both meanings) that would also lead to the current pattern of results.

In addition to the strong heterophone results, this experiment also may shed some light on what happens with ambiguous words that are in between what are commonly referred to as biased and balanced sets. In the homophone conditions, a significant inflation of first pass times on the region following the target word was observed. The homophone conditions led to longer first fixation times (also leading to significantly longer first pass times) than either the heterophone conditions or the control conditions. This suggests that moderately biased homophones experience competition from the subordinate meaning slightly downstream from the target (as opposed to on the target for balanced homophones and not at all for strongly biased homophones). The heterophones do not exhibit this result however, although they are biased to the same degree. One could argue that although sound is a route to meaning that the second (and subordinate) sound code does not activate the second meaning. In moderately biased homophones activation could spread from the initial meaning and sound code to the second meaning. However, although evidence suggests that the second sound code is activated slightly downstream from the heterophone it is not necessary to postulate that activation can spread from that secondary sound code to the secondary meaning. This theory does not necessitate a claim that lexical access is through sound alone. However, it does claim that only meanings that share a sound code with the initially activated meaning are automatically activated, and that a slightly

later activation of the secondary sound code is not good enough to activate the second meaning for heterophones.

If error recovery processes retrieve a short-term memory for a word's pronunciation, then recovery processes should be more difficult for heterophones than homophones since the phonological code available to the readers is incorrect. Experimental results indicated that ambiguous heterophone targets produced much more processing difficulty than ambiguous homophone targets matched on length, frequency, and overall degree of bias towards the dominant meaning, supporting the conclusion that phonology plays an important role in error recovery during sentence comprehension.

In addition, processing difficulty was observed in heterophone conditions immediately after they are encountered, indicating that sound codes in heterophones may be exhaustively accessed.

APPENDIX

FULL SET OF EXPERIMENTAL STIMULI

We found that it was the bows that were applauded after the play that generated all the excitement.

We found that the bows that were applauded after the play generated all the excitement.

We found that it was the bats that were swung in the game that generated all the excitement.

We found that the bats that were swung in the game generated all the excitement.

We found that it was the ants that were crawling in the kitchen that generated all the excitement.

We found that the ants that were crawling in the kitchen generated all the excitement.

Yesterday it was the bows that were applauded after the play that filled James with pride.

Yesterday the bows that were applauded after the play filled James with pride.

Yesterday it was the bats that were swung in the game that filled James with pride.

Yesterday the bats that were swung in the game filled James with pride.

Yesterday it was the ants that were crawling in the kitchen that filled James with disgust.

Yesterday the ants that were crawling in the kitchen filled James with disgust.

In the end it was the bows that were applauded after the play that distracted Jenny from her thoughts.

In the end the bows that were applauded after the play distracted Jenny from her thoughts.

In the end it was the bats that were swung in the game that distracted Jenny from her thoughts.

In the end the bats that were swung in the game distracted Jenny from her thoughts.

In the end it was the ants that were crawling in the kitchen that distracted Jenny from her thoughts.

In the end the ants that were crawling in the kitchen distracted Jenny from her thoughts.

As we had suspected it was the bass that had been swimming in the river that won the fishing contest for Jill.

As we had suspected the bass that had been swimming in the river won the fishing contest for Jill.

As we had suspected it was the deed that had been lying in the safe that won the legal contest for Jill.

As we had suspected the deed that had been lying in the safe won the legal contest for Jill.

As we had suspected it was the cake that had been stored in the pantry that won the baking contest for Jill.

As we had suspected the cake that had been stored in the pantry won the baking contest for Jill.

On Saturday it was the bass that was discovered swimming in the river that was the highlight of the Smith's vacation.

On Saturday the bass that was discovered swimming in the river was the highlight of the Smith's vacation.

On Saturday it was the deed that was discovered lying in the safe that was the highlight of the Smith's vacation.

On Saturday the deed that was discovered lying in the safe was the highlight of the Smith's vacation.

On Saturday it was the cake that was discovered sitting in the pantry that was the highlight of the Smith's vacation.

On Saturday the cake that was discovered sitting in the pantry was the highlight of the Smith's vacation.

As usual, it was the bass that was swimming in the lake that made Joe's eyes sparkle with interest.

As usual, the bass that was swimming in the lake made Joe's eyes sparkle with interest.

As usual, it was the deed that was lying on the desk that made Joe's eyes sparkle with interest.

As usual, the deed that was lying on the desk made Joe's eyes sparkle with interest.

As usual, it was the cake that was baking in the oven that made Joe's eyes sparkle with interest.

As usual, the cake that was baking in the oven made Joe's eyes sparkle with interest.

Unfortunately it was the tear that was ruining my seam that caused me to trip over the child.

Unfortunately the tear that was ruining my seam caused me to trip over the child.

Unfortunately it was the palm that was planted in the pot that caused me to trip over the child.

Unfortunately the palm that was planted in the pot caused me to trip over the child.

Unfortunately it was the root that was growing over the path that caused me to trip over the child.

Unfortunately the root that was growing over the path caused me to trip over the child.

Keith mentioned that it was the tear that was ruining my seam that detracted from the effect of the picture.

Keith mentioned that the tear that was ruining my seam detracted from the effect of the picture.

Keith mentioned that it was the palm that was planted in the pot that detracted from the effect of the picture.

Keith mentioned that the palm that was planted in the pot detracted from the effect of the picture.

Keith mentioned that it was the root that was growing over the path that detracted from the effect of the picture.

Keith mentioned that the root that was growing over the path detracted from the effect of the picture.

We were so bored that it was the tear that was ruining my seam that attracted our attention.

We were so bored that the tear that was ruining my seam attracted our attention.

We were so bored that it was the palm that was planted in the pot that attracted our attention.

We were so bored that the palm that was planted in the pot attracted our attention.

We were so bored that it was the root that was pushing through the path that attracted our attention.

We were so bored that the root that was pushing through the path attracted our attention.

We were all told that it was the lead that could be paid after the production was over.

We were all told that the lead could be paid after the production was over.

We were all told that it was the mold that could be broken after the production was over.

We were all told that the mold could be broken after the production was over.

We were all told that it was the bone that could be returned after the production was over.

We were all told that the bone could be returned after the production was over.

As was customary, it was the lead that would only be paid after the movie was finished.

As was customary, the lead would only be paid after the movie was finished.

As was customary, it was the mold that would only be broken after the statue was finished.

As was customary, the mold would only be broken after the statue was finished.

As was customary, it was the bone that would only be returned after the exhibit was finished.

As was customary, the bone would only be returned after the exhibit was finished.

They were convinced that it was the lead that would be paid after the movie was completed.

They were convinced that the lead would be paid after the movie was completed.

They were convinced that it was the mold that would be broken after the statue was completed.

They were convinced that the mold would be broken after the statue was completed.

They were convinced that it was the bone that would be returned after the exhibit was completed.

They were convinced that the bone would be returned after the exhibit was completed.

In retrospect it was the windy and problematic design of the carving that left us extremely confused.

In retrospect the windy and problematic design of the carving left us extremely confused.

In retrospect it was the rusty and problematic skills of the hiker that left us extremely confused.

In retrospect the rusty and problematic skills of the hiker left us extremely confused.

In retrospect it was the foggy and problematic condition of the roads that left us extremely confused.

In retrospect the foggy and problematic condition of the roads left us extremely confused.

Our video cameras were ready, but it was the windy and underdeveloped design of the carving that made us decide to save our tape for another day.

Our video cameras were ready, but the windy and underdeveloped design of the carving made us decide to save our tape for another day.

Our video cameras were ready, but it was the rusty and underdeveloped skills of the hiker that made us decide to save our tape for another day.

Our video cameras were ready, but the rusty and underdeveloped skills of the hiker made us decide to save our tape for another day.

Our video cameras were ready, but it was the foggy and underdeveloped condition of the roads that made us decide to save our tape for another day.

Our video cameras were ready, but the foggy and

underdeveloped condition of the roads made us
decide to save our tape for another day.
To our dismay it was the windy and
substandard design of the carving that disappointed us.
To our dismay the windy and
substandard design of the carving disappointed us.
To our dismay it was the rusty and
substandard skills of the hiker that disappointed us.
To our dismay the rusty and
substandard skills of the hiker disappointed us.
To our dismay it was the foggy and
substandard condition of the roads that disappointed us.
To our dismay the foggy and
substandard condition of the roads disappointed us.
That particular morning it was the tower that the
tourists paid for the truck that saved the day.
That particular morning the tower that the
tourists paid for the truck saved the day.
That particular morning it was the toast that the
tourists drank for good luck that saved the day.
That particular morning the toast that the
tourists drank for good luck saved the day.
That particular morning it was the sword that the
tourists kept for protection that saved the day.
That particular morning the sword that the
tourists kept for protection saved the day.
Sadly, it was the tower that the couple paid for the truck
that killed them both.
Sadly, the tower that the couple paid for the truck
killed them both.
Sadly, it was the toast that the couple drank at the party
that killed them both.
Sadly, the toast that the couple drank at the party
killed them both.
Sadly, it was the sword that the couple used during the duel
that killed them both.
Sadly, the sword that the couple used during the duel
killed them both.
When the festivities were ending it was the tower that
we paid for the truck that ruined the atmosphere of the
evening.
When the festivities were ending the tower that
we paid for the truck ruined the atmosphere of the
evening.

When the festivities were ending it was the toast that we drank to the hosts that ruined the atmosphere of the evening.

When the festivities were ending the toast that we drank to the hosts ruined the atmosphere of the evening.

When the festivities were ending it was the sword that we defended ourselves with that ruined the atmosphere of the evening.

When the festivities were ending the sword that we defended ourselves with ruined the atmosphere of the evening.

Wandering around, it was the sewer that I found threading her needle that really made my day.

Wandering around, the sewer that I found threading her needle really made my day.

Wandering around, it was the slide that I found stuck in the projector that really made my day.

Wandering around, the slide that I found stuck in the projector really made my day.

Wandering around, it was the grove that I found hidden in the forest that really made my day.

Wandering around, the grove that I found hidden in the forest really made my day.

That autumn day, it was the sewer that was threading her needle that was burned in the fire.

That autumn day, the sewer that was threading her needle was burned in the fire.

That autumn day, it was the slide that was stuck in the projector that was burned in the fire.

That autumn day, the slide that was stuck in the projector was burned in the fire.

That autumn day, it was the grove that was hidden in the forest that was burned in the fire.

That autumn day, the grove that was hidden in the forest was burned in the fire.

On Tuesday, it was the sewer we discovered threading her needle that made us curious.

On Tuesday, the sewer we discovered threading her needle made us curious.

On Tuesday, it was the slide we discovered stuck in the projector that made us curious.

On Tuesday, the slide we discovered stuck in the projector made us curious.

On Tuesday, it was the grove we discovered hidden in the forest that made us curious.

On Tuesday, the grove we discovered hidden in the forest made us curious.

On Easter it was the drawer that had been drafting all night that was exhausted in the morning.

On Easter the drawer that had been drafting all night was exhausted in the morning.

On Easter it was the litter that had been born last night that was exhausted in the morning.

On Easter the litter that had been born last night was exhausted in the morning.

On Easter it was the sailor that had been rowing all night that was exhausted in the morning.

On Easter the sailor that had been rowing all night was exhausted in the morning.

When we entered the hotel it was the drawer that had been sketching all week that greeted us as we walked in the door.

When we entered the hotel the drawer that had been sketching all week greeted us as we walked in the door.

When we entered the hotel it was the litter that had been born last week that greeted us as we walked in the door.

When we entered the hotel the litter that had been born last week greeted us as we walked in the door.

When we entered the hotel it was the sailor that had been away all week that greeted us as we walked in the door.

When we entered the hotel the sailor that had been away all week greeted us as we walked in the door.

We learned the next day it was the drawer that had been sketching for months that tore the house apart.

We learned the next day the drawer that had been sketching for months tore the house apart.

We learned the next day it was the litter that had been born in the spring that tore the house apart.

We learned the next day the litter that had been born in the spring tore the house apart.

We learned the next day it was the sailor that had been on land for months that tore the house apart.

We learned the next day the sailor that had been on land for months tore the house apart.

We discovered in the meeting that it was the recreation that was of the battle at Gettysburg that was going to take longer than anticipated.

We discovered in the meeting that the recreation that was of the battle at Gettysburg was going to take longer than anticipated.

We discovered in the meeting that it was the reservation that was for the Indian tribe that was going to take longer than anticipated.

We discovered in the meeting that the reservation that was for the Indian tribe was going to take longer than anticipated.

We discovered in the meeting that it was the convention that was for the butcher's union that was going to take longer than anticipated.

We discovered in the meeting that the convention that was for the butcher's union was going to take longer than anticipated.

After reading the prospective budgets, it was the recreation that was of the battle at Gettysburg that received its funding.

After reading the prospective budgets, the recreation that was of the battle at Gettysburg received its funding.

After reading the prospective budgets, it was the reservation that was for the Indian tribe that received its funding.

After reading the prospective budgets, the reservation that was for the Indian tribe received its funding.

After reading the prospective budgets, it was the convention that was for the butcher's union that received its funding.

After reading the prospective budgets, the convention that was for the butcher's union received its funding.

After months of hard work it was the recreation that was of the battle at Gettysburg that went off without a hitch.

After months of hard work the recreation that was of the battle at Gettysburg went off without a hitch.

After months of hard work it was the reservation that was for the Indian tribe that went off without a hitch.

After months of hard work the reservation that was for the Indian tribe went off without a hitch.

After months of hard work it was the convention that was for the butcher's union that went off without a hitch.

After months of hard work the convention that was for the butcher's union went off without a hitch.

The day after the storm it was the minute and troubling insects of the region that drove us out of the country.

The day after the storm the minute and troubling insects of the region drove us out of the country.

The day after the storm it was the grave and troubling behavior of the general that drove us out of the country.

The day after the storm the grave and troubling behavior of the general drove us out of the country.

The day after the storm it was the wicked and troubling actions of the soldiers that drove us out of the country.

The day after the storm the wicked and troubling actions of the soldiers drove us out of the country.

After weeks in the pit it was the minute and biting insects of the region that made the prisoners go insane.

After weeks in the pit the minute and biting insects of the region made the prisoners go insane.

After weeks in the pit it was the grave and biting behavior of the general that made the prisoners go insane.

After weeks in the pit the grave and biting behavior of the general made the prisoners go insane.

After weeks in the pit it was the wicked and biting behavior of the guard that made the prisoners go insane.

After weeks in the pit the wicked and biting behavior of the guard made the prisoners go insane.

Even after months of research, it was the minute and mysterious insects of the region that warranted further study.

Even after months of research, the minute and mysterious insects of the region warranted further study.

Even after months of research, it was the grave and mysterious behavior of the general that warranted further study.

Even after months of research, the grave and mysterious behavior of the general warranted further study.

Even after months of research, it was the wicked and mysterious actions of the cult that warranted further

study.

Even after months of research, the wicked and mysterious actions of the cult warranted further study.

The report stated that it was the content of the group of happy people that pleased the mayor greatly.

The report stated that the content of the group of happy people pleased the mayor greatly.

The report stated that it was the hearing of the group of court cases that pleased the lawyer greatly.

The report stated that the hearing of the group of court cases pleased the lawyer greatly.

The report stated that it was the absence of the group of scary bikers that pleased the waiter greatly.

The report stated that the absence of the group of scary bikers pleased the waiter greatly.

It has been argued that it was the content of the array of happy people that made life better in the town.

It has been argued that the content of the array of happy people made life better in the town.

It has been argued that it was the hearing of the array of court cases that made life better in the town.

It has been argued that the hearing of the array of court cases made life better in the town.

It has been argued that it was the absence of the group of scary bikers that made life better in the town.

It has been argued that the absence of the group of scary bikers made life better in the town.

We noticed that it was the content of the set of happy people that made the day special.

We noticed that the content of the set of happy people made the day special.

We noticed that it was the hearing of the set of court cases that made the day special.

We noticed that the hearing of the set of court cases made the day special.

We noticed that it was the absence of the set of scary bikers that made the day special.

We noticed that the absence of the set of scary bikers made the day special.

Ted decided that it was the compact and reliable design of the cars that impressed him the most.

Ted decided that the compact and reliable design of the cars impressed him the most.

Ted decided that it was the fleet and reliable speed of the runners that impressed him the most.

Ted decided that the fleet and reliable speed of the runners impressed him the most.

Ted decided that it was the elegant and reliable service at the hotel that impressed him the most.

Ted decided that the elegant and reliable service at the hotel impressed him the most.

We wanted to leave early, but it was the compact and consistent design of the cars that made us change our minds.

We wanted to leave early, but the compact and consistent design of the cars made us change our minds.

We wanted to leave early, but it was the fleet and consistent speed of the runners that made us change our minds.

We wanted to leave early, but the fleet and consistent speed of the runners made us change our minds.

We wanted to leave early, but it was the elegant and consistent service at the hotel that made us change our minds.

We wanted to leave early, but the elegant and consistent service at the hotel made us change our minds.

We predicted that it was the compact and efficient design of the cars that would be remembered.

We predicted that the compact and efficient design of the cars would be remembered.

We predicted that it was the fleet and efficient speed of the runners that would be remembered.

We predicted that the fleet and efficient speed of the runners would be remembered.

We predicted that it was the elegant and efficient service at the hotel that would be remembered.

We predicted that the elegant and efficient service at the hotel would be remembered.

NOTES

¹Since the current data set contained three out of the four heterophones used in Folk and Morris (1995), those items were examined separately to ascertain if they showed any immediate slowdown. The first fixation means were 278ms for heterophones, 262ms for homophones and 266ms for controls (averaged over focus conditions). The first fixation results were not significant. The first pass means were 308ms for heterophones, 279ms for homophones and 289ms for controls. The main effect of ambiguity was significant by subjects, but it was not significant by items. However, the results for these three items are suggestive that it may have been the particular items used in Folk and Morris (1995) that were responsible for the first fixation and gaze duration inflations on the heterophone targets.

²This effect and the subsequent homophone effect were also significant in first pass times. Since first pass times include first fixation data, and the result was significant in first fixation only the more immediate first fixation data was reported in the body of the paper. The main effect of ambiguity was significant in first pass times, $F_1(1,70) = 9.02$, $MSe = 3,953$, $F_2(1,70) = 5.60$, $MSe = 4,804$. Further analysis indicated that homophones were significantly inflated over control conditions, $F_1(1,35) = 22.10$, $MSe = 6,250$, $F_2(1,35) = 9.63$, $MSe = 5,357$.

³There were no significant homophone effects in the end of sentence region when the data was analyzed on its own. The results for the expanded disambiguation region thus clearly reflect a mixture of effects from both the original disambiguation region and the original end of sentence region.

⁴The go past effect for heterophones observed in the original disambiguation region was also significant in the expanded disambiguation region. The main effect of ambiguity was significant, $F_1(1,70) = 34.42$, $MSe = 369,762$, $F_2(1,70) = 13.73$, $MSe = 754,926$. Further analysis indicated that heterophones were significantly inflated over both homophones, $F_1(1,35) = 30.44$, $MSe = 498,928$, $F_2(1,35) = 13.25$, $MSe = 954,411$ and controls, $F_1(1,35) = 45.37$, $MSe = 491,671$, $F_2(1,35) = 17.53$, $MSe = 1,025,478$. Homophones were not significantly inflated over controls, but instead showed inflation in regression measures. There were no significant effects in the first pass measure on the expanded disambiguation region. This is to be expected, since the expanded region is very large; the first pass effects that existed in the original region were washed out by the high total first pass times on the expanded region.

⁵The results on just the target were entirely consistent with the analyses presented, but could have been confounded by regressions from regions before participants read the disambiguating information. Analysis of the percent regressions into just the target word displayed a main effect of ambiguity, $F_1(1,70) = 25.13$, $MSe = 441$, $F_2(1,70) = 26.98$, $MSe = 390$. Further analysis indicated that this effect was due to all three conditions being different from each other. The heterophone conditions were inflated over the homophone conditions, $F_1(1,35) = 13.54$, $MSe = 585$, $F_2(1,35) =$

13.48, $MSe = 525$, heterophones were inflated over controls, $F_1(1,35) = 53.20$, $MSe = 411$, $F_2(1,35) = 69.15$, $MSe = 301$, and homophones were inflated over controls, $F_1(1,35) = 10.58$, $MSe = 327$, $F_2(1,35) = 10.59$, $MSe = 343$. The analyses on the second pass times on the target word alone (after the region has been passed to the right) revealed a main effect of ambiguity, $F_1(1,70) = 49.10$, $MSe = 13,033$, $F_2(1,70) = 32.58$, $MSe = 18,548$. Further analysis indicated that this effect was due to all three conditions being different from each other. The heterophone conditions were inflated over the homophone conditions, $F_1(1,35) = 43.42$, $MSe = 17,600$, $F_2(1,35) = 25.53$, $MSe = 28,164$, heterophones were inflated over controls, $F_1(1,35) = 65.56$, $MSe = 17,102$, $F_2(1,35) = 56.21$, $MSe = 18,870$, and homophones were inflated over controls (marginal by items), $F_1(1,35) = 7.77$, $MSe = 4,395$, $F_2(1,35) = 3.85$, $MSe = 8,609$, $p = .06$.

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