Phonological and Semantic Ambiguity Resolution During Text Integration

Ranada T. Harrison

Jocelyn R. Folk*

Kent State University

Text integration errors can occur when a reader initially selects the contextually inappropriate meaning of an ambiguous word. When the reader attempts to integrate that meaning into the context, the sentence will not make sense. We investigated how readers recover from text integration errors in an oral reading study involving 2 types of ambiguous words: heterophones and homophones. Heterophones have 2 possible pronunciations and 2 meanings (e.g., sewer*), whereas homophones have 1 pronunciation and 2 meanings (e.g.,* calf*). We hypothesized that the multiple phonological codes of heterophones will cause additional difficulty initially and in recovery from text integration errors compared to homophones. Presumably, the working-memory code involved in reading is sound based (Daneman & Carpenter, 1983), so readers may reread to recover the alternative meaning and pronunciation of a heterophone but not of a homophone with a single pronunciation. We found that skilled readers made more errors initially on heterophones than homophones and used different strategies to recover from text integration errors caused by heterophone and homophone ambiguity.*

Reading is a complex process that involves understanding the semantics (meaning) and phonology (sounds) of words, but also involves integrating the meanings of individual words to extract the overall meaning of phrases and sentences. Text integration is the process of integrating the meaning of phrases and sentences to achieve comprehension (Haberlandt, 1994). Ambiguous words, words having more than one meaning, contribute to reading's complexity (Duffy, Morris, & Rayner, 1988). Ambiguous words appear in many languages and can cause semantic misinterpretations by readers. Over the past few years, psycholinguists have done extensive research on ambiguity as it affects the text integration process.

There are several types of ambiguous words that could affect the text integration process. For example, a word can have multiple semantic interpretations (e.g., *calf)* or multiple meanings and pronunciations (e.g., *sewer)*. The complexity of ambiguous words causes them to be processed differently than nonambiguous words (Duffy et al., 1988; Folk & Morris, 1995; Grainger & Ferrand, 1994; Morris & Folk, 2000), but little research has examined whether different types of ambiguous words are processed differently in reading.

Lexical–Semantic Ambiguity

Psycholinguists have investigated how readers activate the different meanings of semantically ambiguous words (e.g., Duffy et al., 1988, Folk & Morris, 1995; Miyake, Just, & Carpenter 1994; Morris & Folk, 2000; Swinney, 1979; Wiley & Rayner, 2000). By relying heavily on the cross-modal priming paradigm, researchers have examined how homophones, words with more than one possible meaning, but a single spelling, and pronunciation (e.g., *calf),* are processed. In this paradigm, participants listen to a sentence that contains a homophone that is immediately followed by a word that appears on a computer screen that is related to one of the homophone meanings (Swinney, 1979). The findings of Swinney (1979) and many others revealed that when the target word immediately followed the homophone, participants made faster lexical decisions about the target word if

Author note. Ranada T. Harrison and Jocelyn R. Folk, Department of Psychology, Kent State University.

We presented portions of these data at the 14th Annual Ohio Undergraduate Psychology Conference at Mount Union College, Alliance, Ohio, in April 2001.

Correspondence concerning this article should be addressed to Ranada T. Harrison, 1026 East Hyde Park Boulevard, Apartment 3N, Chicago, Illinois 60615. Electronic mail may be sent to rtharrison@consultant.com or jfolk@kent.edu.

 *Faculty Supervisor

it was semantically related to either homophone meaning than if the target word was not semantically related to either homophone meaning (e.g., Kintsch & Mross, 1985; Onifer & Swinney, 1981; Seidenberg, Tanenhaus, Leiman, & Bienkowski, 1982; Swinney, 1979). This finding indicates that both meanings of ambiguous words are initially active.

Recent evidence from eye-tracking studies has suggested that both context and meaning dominance influence readers' processing of ambiguous words. In a series of studies, investigators examined the role of context in ambiguity resolution (Binder & Morris, 1995; Binder & Rayner, 1998; Dopkins, Morris, & Rayner, 1992; Duffy et al., 1988; Rayner & Duffy, 1988; Rayner & Frazier, 1989; Sereno, Pacht, & Rayner, 1992). As readers silently read sentences containing homophones, an eye tracker recorded readers' eye movements and fixation times. Researchers used either biased homophones, having one dominant or more frequent interpretation, or balanced homophones, having two equally likely meanings. When context prior to the ambiguous word was neutral, not providing any clues to the contextually appropriate meaning, findings revealed longer fixation times on balanced homophones than on biased homophones and control words. When the homophone is balanced, both meanings are equally available so they are in competition with each other for selection, slowing initial processing (Binder & Morris, 1995). With biased homophones, there is no competition initially among meanings because one meaning takes precedence over the other. The reader initially selects the dominant meaning of the homophone with little competition from the less likely meaning. In addition researchers found that when readers reach the disambiguating region of the sentence, the region revealing the appropriate meaning of the homophone, participants spent more time in that region when the homophone was biased and the sentence supported the subordinate meaning (Rayner, Pacht, & Duffy, 1994). Readers must spend time recovering the contextually appropriate meaning after initially selecting the contextually inappropriate dominant meaning.

In contrast, when prior context supported the less likely meaning of a biased homophone, readers fixated longer on the biased homophones than on the controls or balanced homophones (Duffy et al., 1988; Rayner et al., 1994). Presumably, the context boosts the activation of the subordinate meaning to compete with the dominant meaning. In summary, these findings suggest that meaning dominance and context influence the processing of biased and balanced homophones.

Phonologically Ambiguous Words

Heterophones, which are semantically and phonologically ambiguous, are processed differently than homophones, and some researchers have attributed this to working-memory processes (Daneman & Carpenter, 1983; Folk & Morris, 1995; Morris & Folk, 2000). Working memory contributes to the acquisition and processing of language, temporarily processing and storing information. Baddeley and Hitch (1974) suggested that working memory influences a range of complex cognitive activities and is important in both language processing and comprehension. The processing code for working memory during reading is believed to be sound based. Thus, some researchers have predicted that recovering from text integration errors for heterophones would be more difficult than for homophones (Daneman & Carpenter, 1983). For heterophones, readers have to retrieve the alternative pronunciation to access the alternative meaning, but they have the sound code associated with both meanings of a homophone in working memory.

Daneman and Carpenter (1983) completed an experiment using *garden path* messages to observe how heterophones and homophones are processed. Garden path messages are passages that prime the reader to expect that one meaning of an ambiguous word is intended and that subsequently indicate that the alternative meaning is contextually correct. This research illustrated the importance of phonology in working memory. Daneman and Carpenter presented two passages to participants and encouraged them to read each one aloud. One passage contained a heterophone or its unambiguous control word, and the other passage contained a homophone or its control word. After reading each passage, the experimenter asked the reader a comprehension question to reveal if he or she correctly or incorrectly interpreted the heterophone or homophone. Daneman and Carpenter defined text integration errors as a result of selecting the contextually incorrect meaning of an ambiguous word. Readers had longer reading times and more text integration errors for text containing heterophones compared to homophones. These results indicate that readers had more difficulty recovering from heterophone misinterpretations than homophone misinterpretations. Presumably, the reader has more difficulty initially reading and recovering from errors caused by heterophones (multiple pronunciations) than homophones (single pronunciations) because the working-memory code is sound based. The multiple pronunciations of heterophones cause confusion in working memory.

To recover from incorrect interpretations of heterophones, the reader must retrieve all the phonological codes of the word and then reinterpret the word (Folk & Morris 1995; Morris & Folk, 2000). This explanation of how readers recover is based on current models of reading that suggest that readers hold the sound codes of words read in working memory (Baddeley & Hitch, 1974; Gathercole & Baddeley, 1993). Working memory contributes to the acquisition and processing of language, temporarily processing and storing information. Baddeley and Hitch (1974) suggested that working memory influences a range of complex cognitive activities and is important in both language processing and comprehension. The processing code for working memory is believed to be sound based. If current reading models are accurate, the reader would not be able to convert from one meaning to the other without accessing the additional pronunciation.

Folk and Morris (1995) also observed processing differences among readers when reading sentences containing heterophones and homophones. They recorded participants' eye movements during silent reading. Folk and Morris examined the target word region and the disambiguating region of each sentence to observe processing time. The target region consisted only of the target word (i.e., ambiguous heterophones and homophones or their unambiguous controls), and the disambiguating region consisted of any words or phrases in the sentence that biased toward one interpretation of the ambiguous word. The context prior to the ambiguous word was neutral, and the disambiguating region followed the ambiguous word. Folk and Morris found that participants reread heterophones more often than unambiguous control words, but not homophones. This finding is consistent with Daneman and Carpenter's (1983) findings, suggesting that readers have more difficulty recovering from text integration errors involving heterophones than homophones.

Why do readers have more difficulty reading sentences containing heterophones than homophones? While reading, readers place the word's phonological codes in working memory, allowing for the word to be integrated with subsequent text so they can obtain the overall meaning of the text (Gathercole & Baddeley, 1993). If a reader selects the dominant meaning of a heterophone, phonological working memory maintains the sound code. As readers continue to read, reaching the disambiguating region, they realize that the dominant meaning is semantically inappropriate. More effort is needed for heterophone text integration error recovery than homophone text integration error recovery because heterophones have two phonological codes and homophones have one phonological code. Thus, readers will need to expend more effort for recovery. Heterophone text integration recovery requires accessing all possible phonological codes for the word to gain the correct meaning (Folk & Morris, 1995). Homophone text integration recovery gives readers the capability to convert from an incorrect meaning to a correct meaning using the same phonological code (Folk & Morris, 1995). The findings from the studies of Daneman and Carpenter (1983) and Folk and Morris (1995) led us to the current experiment in which we (a) observed how skilled readers resolve phonological and semantic ambiguity and (b) examined how homophone (multiple meanings and one pronunciation) and heterophone (multiple meanings and multiple pronunciations) ambiguity affect text integration.

Current Study

Based on findings of previous research, we hypothesized that differences in heterophone and homophone text integration is a result of the reader's working-memory code (Daneman & Carpenter, 1983; Folk & Morris, 1995). "The water treatment manager forgot to visit the *sewer* on 125th Street to pick up his tuxedo." When reading this sentence, if readers initially interpret *sewer* (heterophone) as a drainage tunnel, they may encounter an integration error. After reading "his tuxedo," the disambiguation region of the text, the readers realize they have selected a meaning that is not semantically appropriate with the remaining text; this realization begins the recovery process. The recovery process we observed was rereading. We hypothesized that the ease of recovery from a text integration error will significantly depend on the ambiguity type—heterophone or homophone—because of the phonological ambiguity of heterophones.

The present experiment investigated the influence of ambiguity type on initial word errors and the rate of rereading. We examined how readers recover from integration errors involving the misinterpretation of ambiguous words. Readers were presented with sentences that contained ambiguous homophones or heterophones. Initial context was consistent with the dominant interpretation of an ambiguous word, with the subsequent context consistent with the less likely subordinate meaning. We expected more processing difficulties with text containing heterophones (e.g., *sewer)* than homophones (e.g., *calf)* when examining the initial word errors and rereading rate because phonological codes impact the text integration process (Daneman & Carpenter, 1983; Folk & Morris, 1995; Morris & Folk, 2000).

TABLE 1

Example Sentences

	Example sentences
Homophone example	
Ambiguous word	As the accountant observed the *bill* on the duck he noticed that it had very unique features.
Control word	As the accountant observed the *hair* on the lion he noticed that it had very unique features.
Heterophone example	
Ambiguous word	The water treatment manager forgot to visit the *sewer* on 125th Street to pick up his tuxedo.
Control word	The water treatment manager forgot to visit the *tailor* on 125th Street to pick up his tuxedo.

Note. The target word is indicated by italics, and the disambiguating region is underlined.

Method

Participants

Fifty-eight Kent State University undergraduates from the Psychology Department participant pool served as participants. Participants received course credit in exchange for participating in the experiment. Experiment eligibility required that all participants be native English speakers with no reported reading disabilities. Student ages ranged from 18 to 31, with the majority of students in the 18- to 21-year-old range. Both men and women participated, with the majority of participants being women.

Materials

We used five heterophones (e.g. *sewer:* tailor/gutter), five homophones (e.g. *calf:* leg/cow) and 10 control words in our oral reading experiment (see Appendix). We matched unambiguous control words with the ambiguous words in length and frequency. Mean length is the average number of letters per word, and mean frequency refers to how frequently a word is used in print. We used the Francis and Kucera (1982) written word frequency norms to determine word frequency. The mean length for heterophones was 4.6 letters, and mean frequency was 41.6 occurrences per million words according to the Francis and Kucera norms (mean length for their unambiguous control words was 4.6 letters, and mean frequency was 37.2). The mean length for homophones was 4.6 letters, and the mean frequency was 131.8. The mean length for the control words was 4.6 letters, and the mean frequency was 122.6. We used local population norms to determine the meaning bias of ambiguous words. We used only biased ambiguous words, words with one meaning more frequent than the other.

We embedded all ambiguous and control words in sentences in which the text before the ambiguous word was in agreement with the dominant meaning of the word and in which the subsequent text, called the disambiguating region, was consistent with the less likely subordinate meaning. Our materials consisted of 20 experimental sentences: 5 sentences containing heterophones, 5 sentences containing homophones, and 10 control sentences. In addition, we included 60 filler sentences, sentences that did not contain ambiguous words or control words. We used filler sentences to ensure that readers did not notice the purpose of the experiment. Example sentences are contained in Table 1.

Apparatus

We used a Sony auto-reverse cassette recorder, Sony tiepin lapel microphone, and Sony high-fidelity normal-bias audiocassettes to record oral reading responses. Each sentence was on a single sheet of paper and was presented one at a time. We bound sentences in a three-ring binder.

Design and Procedure

The experimenter informed participants that they were participating in an oral reading experiment, tested each participant individually, and encouraged participants to read as they normally do for sentence comprehension. The booklet with the experimental sentences contained "yes" or "no" comprehension questions that followed some of the filler sentences and required an oral response. Participants read eight practice sentences so that they were familiar with the procedure before reading the experimental materials. After reading each sentence aloud, the participants turned the page and then read the remainder of the sentences. All participants performed the experiment at their own pace.

We presented the sentences in a pseudo-randomized order. We used four presentation orders for the sentences and assigned participants to conditions by using a Latin square design. We used comprehension questions as a check to make sure that participants read the text for comprehension, and the experimenter recorded the participants' responses to the comprehension questions manually, in addition to the audio recording. To be included in the study, a participant had to answer 85% of the comprehension questions correctly. Six participants did not meet this comprehension criterion, and we excluded their data from the analyses.

Results

We collected two dependent measures: initial word errors and rereading. We defined initial word errors as any reading errors occurring when the reader first encountered the ambiguous words or control words. We included long pauses (i.e., an extended period of silence after reading the target word before proceeding onto the next word), hesitations (i.e., an extended period of silence before reading the target word), stumbling on the word, and mispronunciations as initial word errors. We used the following criterion for scoring initial word errors: If the reader initially said the subordinate meaning of the ambiguous word, we coded the response as incorrect. This criterion for scoring is somewhat controversial because the subordinate meaning was the contextually appropriate meaning, but the reader was not aware that the subordinate meaning was correct until after initially encountering the ambiguous word. The second dependent measure was rereading (i.e., any rereading of an ambiguous or control word after initially encountering the word). Two raters scored all of the initial word errors and rereading. Reliability between the raters was .80.

We excluded one homophone and its control word from the analyses. Many participants mispronounced the homophone *coach* initially as *couch,* and several participants said that the sentences with *coach* contained a spelling error. Thus, we excluded *coach* and its control word from the analyses because *coach* was not an ambiguous word to many of our participants. The participants were unfamiliar with the "traveling compartment" meaning of *coach.*

TABLE 2

Proportion of Initial Errors and Rereading of Heterophones, Homophones, and Control Words

	Ambiguity type			
	Heterophones		Homophones	
Word type	IE	RR	IE	RR
Ambiguous	.76	.10	.01	.06
Control	.02	.01	.03	.00
Difference	+.74	+.09	–.03	+.06

Note. IE = initial errors, and RR = proportion of times the word was reread.

For initial word errors we performed a 2 (type of ambiguity: heterophone or homophone) × 2 (word type: ambiguous or control) within-participants analysis of variance (ANOVA; see Table 2 for means). In this analysis, the main effect of ambiguity was significant, $F(1, 51) = 250.00$, $MSE = .03$, $p < .001$. The main effect of word type was also significant, $F(1, 51) = 311.30$, $MSE = .02$, $p < .001$, because readers made more initial errors on the ambiguous words than on the controls. The interaction was also significant, $F(1, 51) = 238.62$, $MSE = .03$ $p < .001$, as readers made more errors on the heterophones versus controls than on the homophones versus controls. We discovered that the processing of heterophones was different than their controls in a planned comparison, $F(1, 51) = 346.30$, $MSE = .04$, $p < .01$, as we found more initial errors on heterophones than on their controls. Among the processing of homophones and their controls there was no significant difference, $F(1, 51) = 2.88$, $MSE = .01$, $p = .10$. The multiple phonological codes of heterophones caused the differences in difficulty between initial word errors for heterophones and homophones because both heterophone pronunciations are initially active and competing for selection.

We performed a second ANOVA for the rereading data (see Table 2 for means). The main effect of ambiguity was not significant, $F(1, 51) = 2.26$, $MSE = .02$, $p > .13$. The main effect of word type was significant, $F(1, 51) = 8.55$, $MSE = .04$, $p < .01$, because readers reread the ambiguous words more than the control words. The interaction was not significant,

$F(1, 51) = 1.25$, $MSE = .02$, $p > .26$. In planned comparisons, we found that readers reread the heterophones more than control words, $F(1, 51) = 10.17$, $MSE = .02$, $p < .01$. However, rereading of homophones did not differ from that of their control words, $F(1, 51) = 3.12$, $MSE = .03$, $p > .08$.

Discussion

The present results provide evidence that heterophones and homophones are processed differently, consistent with previous studies (Daneman & Carpenter, 1983; Folk & Morris, 1995; Morris & Folk, 2000). The processing differences among heterophones and homophones are evident in the documentation of more errors initially on heterophones versus their controls than on homophones versus their controls. This finding suggests that readers initially have both phonological codes for heterophones available. When reading heterophones, the phonological codes compete with each other for selection, causing initial pronunciation errors.

Any time the reader read the target or control word and then proceeded past the target of control word to other words and then returned back to the target of control word, we coded this as rereading. In our initial analysis of the data, the rereading of the heterophones and homophones are both significantly elevated relative to their unambiguous controls. However, we found that the inclusion of *coach* caused the increased rereading in homophones. When initially reading *coach,* many readers interpreted it as *couch* and read the word as *couch*. We believe that the elevated rereading on this homophone can be attributed to participants not knowing both meanings of *coach* (team/wagon). When we removed *coach* from the data, the analysis of the results revealed that the homophone effect disappeared, as did most of the rereading on the homophones. Importantly, the rereading difference on homophones and their controls was no longer significant. This finding suggests that readers are more likely to reread heterophones than homophones, supporting our hypothesis that readers recover differently from text integration errors caused by heterophones than by homophones, with rereading more likely for heterophones.

As previously discussed, working memory influences these differences in processing, as working memory is sound based in reading. The reader uses his or her working memory to store the phonological code and meaning of a word. Readers must make a decision about the pronunciation of the word and meaning when reading heterophones, but when reading homophones only a distinction between multiple meanings is necessary.

The results of our experiment will assist in helping to better understand "normal" reading errors and reading deficiencies and provide a more extensive illustration of the error recovery process. Understanding of the recovery process of text integration errors will help refine current models of reading and provide descriptive information about the recovery process. Future experiments could involve embedding ambiguous words and control words into longer garden path messages than we used. The embedding of ambiguous or control words in longer messages will provide the reader with additional context, biasing the reader's selection of one meaning over another, unlike our current materials that just offer a short phrase to bias the reader to one meaning. If we can bias the reading to one meaning more strongly, we would possibly gather a better observation of initial errors and recovery methods.

References

Baddeley, A. D, & Hitch, G. (1974). Working memory. In G. H. Bower (Ed.), *The psychology of learning and motivation: Advances in research and theory* (Vol. 8, pp. 47–89). New York: Academic Press.

Binder, K. S., & Morris, R. K. (1995). Eye movements and lexical ambiguity resolution: Effects of prior encounter and discourse topic. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 21,* 1186–1196.

Binder, K. S., & Rayner, K. (1998). Contextual strength does not modulate the subordinate bias effect: Evidence from eye fixations and self-paced reading. *Psychonomic Bulletin and Review, 5,* 271–276.

Daneman, M., & Carpenter, P. A. (1983). Individual differences in integrating information between and within sentences. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 9,* 561–584.

Dopkins, S., Morris, R. K., & Rayner, K. (1992). Lexical ambiguity and eye fixations in reading: A test of competing models of lexical ambiguity resolution. Journal of Memory and Language, 31, 461–476.

Duffy, S. A., Morris, R. K., & Rayner, K. (1988). Lexical ambiguity and fixation times in reading. *Journal of Memory and Language, 27,* 429–446.

Folk, J. R., & Morris, R. K. (1995). Multiple lexical codes in reading: Evidence from eye movements, naming time, and oral reading. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 21,* 1412–1429.

Francis, W. N., & Kucera, H. (1982). *Frequency analysis of English usage: Lexicon and grammar.* Boston: Houghton Mifflin.

Gathercole, S. E., & Baddeley, A. D. (1993). *Working memory and language.* Hillsdale, NJ: Erlbaum.

Grainger, J., & Ferrand, L. (1994). Phonology and orthography in visual word recognition: Effects of masked homophone primes. *Journal of Memory and Language, 33,* 218–233.

Haberlandt, K. (1994). Methods in reading research. In M. A. Gernsbacher (Ed.), *Handbook of psycholinguistics* (pp. 1–31). New York: Academic Press.

Kintsch, W., & Mross, E. F. (1985). Context effects in word identification. *Journal of Memory and Language, 24,* 336–349.

Miyake, A., Just, M. A., & Carpenter, P. A. (1994). Working memory constraints on the resolution of lexical ambiguity: Maintaining multiple interpretations in neutral contexts. *Journal of Memory and Language, 33,* 175–202.

Morris, R. K., & Folk, J. R. (2000). Phonology is used to access word meaning during silent reading: Evidence from lexical ambiguity resolution. In A. Kennedy, R. Radach, D. Heller, & J. Pynte (Eds.), *Reading as a perceptual process* (pp. 427–446). Amsterdam: Elsevier Press.

Onifer, W., & Swinney, D. A. (1981). Accessing lexical ambiguities during sentence comprehension: Effects on frequency of meaning and contextual bias. *Memory & Cognition, 9,* 225–236.

Rayner, K., & Duffy, S. A. (1988). On-line comprehension processes and eye movements during reading. In M. Daneman, G. E. MacKinnon, & T. G. Waller (Eds.), *Reading research: Advances in theory and practice* (Vol. 6, pp. 13–66). New York: Academic Press.

Rayner, K., & Frazier, L. (1989). Selection mechanisms in reading lexically ambiguous words. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 15,* 779–790.

Rayner, K., Pacht, J. M., & Duffy, S. A. (1994). Effects of prior encounter and global discourse bias on the processing of lexically ambiguous words: Evidence from eye fixations. *Journal of Memory and Language, 33,* 527–544.

Seidenberg, M. S., Tanenhaus, M. K., Leiman, J. M., & Bienkowski, M. (1982). Automatic access of the meanings of ambiguous words in context: Some limitations of knowledge-based processing. *Cognitive Psychology, 14,* 489–537.

Sereno, S. C., Pacht, J. M., & Rayner, K. (1992). The effect of meaning frequency on processing lexically ambiguous words: Evidence from eye fixations. *Psychological Science, 3,* 296–300.

Swinney, D. A. (1979). Lexical access during sentence comprehension: (Re)consideration of context effects. *Journal of Verbal Learning and Verbal Behavior, 18,* 645–659.

Wiley, J., & Rayner, K. (2000). Effects of titles on the processing of text and lexically ambiguous words: Evidence from eye movements. *Memory & Cognition, 28,* 1011–1021.

APPENDIX

Ambiguous Words and Their Unambiguous Control Words Included in the Study

Heterophones	**Heterophone Controls**
Wound	Swept
Sewer	Tailor
Bow	Rod
Shower	Escort
Tear	Rip
Homophones	**Homophone Controls**
Coach	Cabin
Bill	Hair
Table	Chart
Scales	Stones
Bank	Edge