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Eye Movements and Lexical Ambiguity Resolution: Investigating the Subordinate-Bias Effect

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Recent debates on lexical ambiguity resolution have centered on the *subordinate-bias effect,* in which reading time is longer on a biased ambiguous word in a subordinate-biasing context than on a control word. The nature of the control word—namely, whether it matched the frequency of the ambiguous word's overall word form or its contextually instantiated word meaning (a higher or lower frequency word, respectively)—was examined. In addition, contexts that were singularly supportive of the ambiguous word's subordinate meaning were used. Eye movements were recorded as participants read contextually biasing passages that contained an ambiguous word target or a word-form or word-meaning control. A comparison of fixation times on the 2 control words revealed a significant effect of word frequency. Fixation times on the ambiguous word generally fell between those on the 2 controls and were significantly different than both. Results are discussed in relation to the reordered access model, in which both meaning frequency and prior context affect access procedures.

Keywords: eye movements, ambiguity, lexical access, context, subordinate-bias effect

It is not a matter of debate that higher level contextual factors influence word recognition. What is controversial is when these factors come into play. Whether contextual effects are early- or late-acting has implications for the circuitry of language processing and for cognitive–brain processing in general. Lexically ambiguous words possess a single orthographic form but more than one meaning and, as such, retain a significant status in determining how and when word meaning is integrated into a developing discourse context.

A great deal of ambiguity research has used the cross-modal priming paradigm, with auditory presentation of a context and an ambiguous word followed by visual presentation of a probe word related to either the contextually appropriate or inappropriate meaning of the ambiguous prime (Swinney, 1979; Tanenhaus, Leiman, & Seidenberg, 1979). When the probe is presented immediately after offset of the ambiguous prime, priming to both contextually appropriate and inappropriate meanings occurs relative to an unrelated control; when the probe is delayed by 200 ms or more, priming to only the appropriate meaning occurs. Such results have generally been interpreted as supporting *exhaustive access* and the modularity of lexical processing, in which context only operates after a later, postlexical stage of processing after all meanings have been initially accessed (e.g., Fodor, 1983; Forster, 1979). However, some research is more consistent with *selective access* and interactivity, in which context directs the early, lexical selection of the appropriate meaning (e.g., McClelland, 1987; Morton, 1969). Furthermore, Lucas (1999) demonstrated that when results were combined across several cross-modal studies, the contextually appropriate meaning was consistently more strongly activated (see also McClelland, 1987). Finally, there are some reasons for doubting how far this paradigm can be used to explain word activation in the course of fluent reading (Sereno, 1995).

Over the past 20 years, eye movement reading research on lexical ambiguity resolution has provided a substantial body of evidence as well as theoretical accounts of how ambiguous words are processed (for a review, see Duffy, Kambe, & Rayner, 2001). In eye movement studies, fixation time on an ambiguous word is compared with fixation time on an unambiguous control word. Fixation time on an ambiguous word depends on certain aspects of the text as well as characteristics of the homograph itself. The first factor that affects fixation time is the location of context. The context can either precede the ambiguous word (*biasing* prior context) or follow it (*neutral* prior context). The second factor is the type of homograph that is used. Ambiguous words have been classified as either *balanced* or *biased,* depending on the relative frequency of alternative meanings (Rayner & Duffy, 1986). Some ambiguous words are balanced, having two salient meanings (and, possibly, other subordinate meanings), but most are biased (or polarized), having one strongly dominant meaning and one or more subordinate meanings. The third factor is the meaning of the ambiguous word that is instantiated by the context. Context can either select the more frequent, *dominant* meaning or the less

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frequent, *subordinate* meaning (this is true even in the case of balanced ambiguous words, because the two meanings are rarely precisely equal in frequency).

Following the initial Rayner and Duffy (1986) study, numerous eye movement studies examining lexical ambiguity resolution have been reported (Binder, 2003; Binder & Morris, 1995; Binder & Rayner, 1998, 1999; Dopkins, Morris, & Rayner, 1992; Duffy, Morris, & Rayner, 1988; Folk & Morris, 2003; Kambe, Rayner, & Duffy, 2001; Rayner, Binder, & Duffy, 1999; Rayner & Frazier, 1989; Rayner, Pacht, & Duffy, 1994; Sereno, 1995; Sereno, Pacht, & Rayner, 1992; Wiley & Rayner, 2000). In general, the findings from such studies can be summarized as follows. When an ambiguous word appears in a neutral context, readers fixate longer on balanced ambiguous words than on biased words or on unambiguous control words. However, when readers encounter the disambiguating information following the target, they spend more time on this region when it supports the subordinate meaning of a biased word compared with any other case. When an ambiguous word appears in a biasing context, the pattern of results is quite different. Fixation times are longer when context supports the subordinate meaning of a biased ambiguous word compared with the dominant meaning of that word, either meaning of a balanced word, or a control word. This has been referred to as the *subordinate-bias effect* (SBE; Pacht & Rayner, 1993; Rayner et al., 1994) and is addressed in detail below.

On the basis of the pattern of eye movement data, two different models have been proposed: the *reordered access* model (Duffy et al., 1988) and the *integration* model (Rayner & Frazier, 1989). These models can be viewed as modified versions of the *interactive* (e.g., McClelland, 1987; Morton, 1969) and *modular* (e.g., Fodor, 1983; Forster, 1979) models, respectively, in that they additionally take into account the ordered activation of alternative meanings according to their meaning dominance (cf. Hogaboam & Perfetti, 1975; Simpson, 1981, 1984; Simpson & Burgess, 1985). As a point of clarification, we use the term *word-form frequency* to refer to the overall rate of occurrence of a word regardless of its meaning(s), and we use *meaning frequency* to refer to the partial frequency of one meaning of an ambiguous word. In both eye movement ambiguity models, alternative meanings become available in the order of their meaning frequencies (i.e., the dominant meaning would always become available first). In the reordered access model, context and meaning frequency influence the speed of lexical access, and thus, it is possible that context reorders the sequence in which an ambiguous word's meanings are accessed for integration into the text representation. In the integration model, meaning frequency alone affects the speed of lexical access; contextual processes only interact with the output of the lexical processor. The weight of results, coupled with experiments explicitly designed to test these models (Dopkins et al., 1992; Sereno, 1995) and simulations of the data patterns (Duffy et al., 2001), indicate that the reordered access model best accounts for the existing data.

Current Issues

Recent debate has centered on the SBE. As mentioned above, this refers to a pattern of results in which reading time is longer on an ambiguous word than it is on an unambiguous control word under the following specific conditions: (a) The ambiguous word is a biased ambiguous word, (b) a prior context instantiates the word's subordinate meaning, and (c) the control word is matched to the overall word-form frequency of the ambiguous word. Using a probe-naming task, Kellas and colleagues have reported that the SBE can be eliminated under various contextual conditions (Kellas & Vu, 1999; Martin, Vu, Kellas, & Metcalf, 1999; Vu & Kellas, 1999; Vu, Kellas, Metcalf, & Herman, 2000; Vu, Kellas, Petersen, & Metcalf, 2003). Rayner and colleagues, however, using eye movements in reading, have been unable to replicate these findings (Binder & Rayner, 1998, 1999; Kambe et al., 2001; Rayner et al., 1999). The reasons for these differences are somewhat unclear and could be related to differences in task, response-time measure, and stimulus materials, though Binder and Rayner (1998) obtained similar results with eye movement and self-paced reading measures.

An eye movement study by Wiley and Rayner (2000) did suppress the SBE under restricted conditions using relatively high-frequency subordinate meanings (8%–30% of the overall meaning; typically, the subordinate meaning of a biased ambiguous word is, on average, less than 10% of the overall meaning). Each of four passages used five ambiguous words. Because each passage was presented under two different title conditions, the contexts could never be explicitly disambiguating and were somewhat vague. For example, the ambiguous word *pitcher* appeared in a passage titled "Worries of a Baseball Team Manager" or "Worries of a Ceramics Factory Manager" (meant to bias either its "baseball" or its "jug" meaning, respectively). Thus, it is possible that readers did not arrive at the intended meaning but, instead, the dominant one. Furthermore, the difficult nature of the passages produced longer reading times, allowing a greater influence for context. Also, the use of titles to establish constraint may well represent an atypical case. It is therefore important to replicate these findings using more standard texts.

The current experiments addressed the findings of a recent eye movement experiment by Kambe et al. (2001) that reaffirmed the presence of the SBE. This experiment is a key one in the literature, because the SBE persisted in the face of what appeared to be extensive contextual priming defined in terms of both global and local contexts. However, Kambe et al.'s design made two assumptions that deserve closer examination. The first, pervasive in the literature, is that the appropriate control word should be matched to the overall word-form frequency of the ambiguous word. The second assumption is that presenting both dominant- and subordinate-biasing contexts for an ambiguous target within the same passage incurs no cost.

In almost all eye movement ambiguity studies, the control word is matched to the overall word-form frequency of the ambiguous word. Sereno et al. (1992) argued that a more appropriate control word may be one matched to the meaning frequency instantiated by the prior context. When the subordinate meaning of an ambiguous word is instantiated, for example, the control word should match its meaning frequency. In practice, this results in control words of lower frequency. There is an extensive literature demonstrating that fixation times are longer on low-frequency (LF) than they are on high-frequency (HF) words (e.g., Rayner & Duffy, 1986; Sereno & Rayner, 2000). From this perspective, the SBE could be regarded as a methodological consequence of the type of control word used. For example, an ambiguous word like *bank* has a highly dominant "money" meaning and a subordinate

"river" meaning. In terms of its overall word form, *bank* is an HF word. However, when *bank* occurs in its "river" instantiation, it has an LF word meaning. Sereno et al. (1992) used ambiguous words like *bank* and two control words—one matched to the frequency of the word form (e.g., *edge*) and one matched to the frequency of the word meaning (e.g., *brim*), an HF and an LF word, respectively. They found that with subordinate-biasing contexts, fixation time on the ambiguous word equaled that of the meaning-frequency (LF) control, and both words were fixated longer than the word-form (HF) control. As such, the presence of the SBE depended on which control word was used as the basis of comparison. However, the pattern of results was less clear for *spillover* fixations—those occurring directly after the target. Sereno et al. (1992) found that such fixations were inflated for the ambiguous condition relative to both control conditions. These results are discussed in more detail below. At this point, however, it is important to note that choosing the appropriate control word is not simply a methodological issue. Computational models have brought the theoretical implications into relief. For example, Duffy et al. (2001) used a constraint-satisfaction approach and demonstrated that the SBE could be the consequence of competition between alternative meanings (see also Twilley & Dixon, 2000). Reichle, Rayner, and Pollatsek (2003; see also Reichle, Pollatsek, & Rayner, in press), however, implemented a two-stage lexical access process within their E-Z Reader model of eye movement control to account for the data of Duffy et al. (1988), with each stage involving varying contributions from word frequency and contextual constraint. To account for the SBE, Reichle and colleagues critically assumed that the subordinate meaning of an ambiguous word was equivalent to an LF word.

The second assumption concerns mixed contexts. In the majority of eye movement studies, ambiguous words appear as targets within single-line sentences. Consequently, the preceding contexts are relatively short, comprising the first half of the sentence. The few studies that have used more substantial, multiline contexts have typically also manipulated whether the context supported only one or both meanings of the ambiguous word. That is, in such studies, half of the experimental items have consisted of paragraphs that initially bias one meaning then switch to biasing the other meaning of the ambiguous target. Table 1 shows example stimuli from the four experimental conditions in the experiment reported by Kambe et al. (2001).

The ambiguous target *boxer* has a dominant "fighter" meaning and a subordinate "dog" meaning. The biasing contexts comprised both an initial, *global* context (the first, topic sentence of each passage) and a later, *local* context (contained in the last sentence along with the target). The local context was always biased toward the subordinate meaning. In addition, the local context could appear either before or after the target. The global context, however, could be biased toward either meaning, leading half of the time to inconsistent passages, as illustrated in the last two passages in Table 1, in which the global context biases the dominant meaning. Although global and local contexts are separated by two filler sentences that are relatively content-free, these transitions nevertheless seem disruptive and could have drawn attention to the nature of the context. It is possible, for example, that as the experiment proceeded, readers may have attempted to either anticipate such plausibility shifts or simply disregard the context, both of which could have affected their reading behavior.

The present investigation addressed the two assumptions of Kambe et al. (2001)—regarding the type of control word and the context—in a series of three replications with certain modifications. As a starting point, only the contextually strongest passages from Kambe et al. were used—that is, ones similar to the first passage in Table 1 (*consistent/before*), in which global and local contexts are congruous, and the local disambiguating information precedes the target. Experiment 1 exclusively used passages from this condition with the original ambiguous and control word tar-

Table 1
Example Stimuli From the Four Experimental Conditions in Kambe, Rayner, and Duffy (2001)

Condition		Stimulus
Consistent/before:	Global subordinate Local subordinate and before target	Sam's pet died last week and he wanted a new companion. He spent a great deal of time reviewing his options. He even went to talk to other people to get their advice. Sam decided to go to a kennel where he bought a boxer that he knew he would like to take home.
Consistent/after:	Global subordinate Local subordinate and after target	Sam's pet died last week and he wanted a new companion. He spent a great deal of time reviewing his options. He even went to talk to other people to get their advice. After awhile Sam made the decision to find a boxer that he knew he would like as a pet and a companion.
Inconsistent/before:	Global dominant Local subordinate and before target	Sam was out of shape and needed to join a gym. He spent a great deal of time reviewing his options. He even went to talk to other people to get their advice. Sam decided to go to a kennel where he bought a boxer that he knew he would like to take home.
Inconsistent/after:	Global dominant Local subordinate and after target	Sam was out of shape and needed to join a gym. He spent a great deal of time reviewing his options. He even went to talk to other people to get their advice. After awhile Sam made the decision to find a boxer that he knew he would like as a pet and a companion.

Note. The two meanings of the ambiguous target *boxer* are the subordinate "dog" meaning and the dominant "fighter" meaning. The global context is the topic or first sentence of each passage, and the local context is contained within the target or last sentence. The local context can occur before or after the target (which is underlined).

gets. It seemed reasonable to assume that eliminating inconsistent passages within an experiment would serve to strengthen the role of context. Experiment 2 used identical passages but exchanged the original word-form (HF) control for a word-meaning (LF) control word, equivalent in frequency to the contextually instantiated subordinate meaning of the ambiguous word. Finally, Experiment 3 used modified (shortened) versions of the consistent/before passages with all three targets—ambiguous, word-form (HF), and word-meaning (LF) control words. Additional passages were created to accommodate the use of both controls. The presence of both controls in a single experiment not only served to replicate Experiments 1 and 2 but also allowed for an independent examination of the word-frequency effect. Across the three experiments, it was hypothesized that our use of stronger (congruous) contexts, in comparison with previous studies, would attenuate the SBE with respect to the word-form (HF) control and would eliminate the SBE with respect to the word-meaning (LF) control, as in Sereno et al. (1992).

Experiment 1

Experiment 1 examined the SBE within a subset of Kambe et al.'s (2001) materials. Of their four original conditions (see Table 1), only consistent/before passages were used. This was the strongest contextual condition, because both global and local contexts preceded and supported the subordinate meaning of the ambiguous target. Fixation-time measures for ambiguous words were compared with those for control words matched to their overall word-form frequency.

Method

Participants. Eighteen members of the University of Massachusetts at Amherst community either received experimental course credit or were paid ($8/hr) for their participation. The average age of participants was 26 years (range: 18–40); 11 were female, and 7 were male. They all had normal or corrected-to-normal vision and were naive concerning the purpose of the experiment.

Materials. There were 24 ambiguous targets (for full details, see Kambe et al., 2001). These were biased ambiguous words, with average component meaning values of 90% (range: 83%–99%) for the dominant meaning and 6% (range: 1%–14%) for the subordinate meaning as assessed from local (University of Massachusetts at Amherst) and published (e.g., Twilley, Dixon, Taylor, & Clark, 1994) norms. Each ambiguous word was paired with an unambiguous control word that was matched in word length, word frequency, and semantic fit within the passage. The average length for both ambiguous and control words was 4.96 characters. The average overall word-form frequency, as computed from the Francis and Kučera (1982) norms, was 65 per million for ambiguous words and 64 per million for control words.[1]

The passages were a subset of those used in Kambe et al. (2001). Kambe et al.'s experiment had four conditions, which are delineated in Table 1. Only consistent/before passages were chosen for the present research. Each passage contained an initial topic sentence or global context that supported the subordinate meaning of a later occurring ambiguous target. This was followed by two filler sentences that were relatively content-free, contrived to separate global from local contexts. The last sentence of each passage opened with a local context, followed by the target and the remainder of the sentence. For each of the 24 pairs, Kambe et al. had constructed two different passages, Versions A and B, both of which could accommodate either target. Thus, there were 48 passages in total.

Although the Appendix lists the full set of materials for Experiment 3, it contains the materials for Experiment 1 with one exception. The two intervening filler sentences between global and local contexts within each passage that were present in Experiment 1 were removed in Experiment 3 and, hence, do not appear in the Appendix. Although three targets are listed in the Appendix for each of the 24 sets of passages, only the first two (ambiguous and word-form [HF] control) were used in Experiment 1.

Design. Two sets of 48 passages were devised. In Set 1, ambiguous words appeared in the A versions and controls appeared in the B versions (see the Appendix). The inverse mapping held for Set 2. One half of the participants read Set 1 passages, and the other half read Set 2 passages. In this way, each participant was presented with all ambiguous and control words, each in a different passage. With two experimental conditions—ambiguous and word-form (HF) control—there was a possible total of 24 data points per participant per condition.

Apparatus. Participants' eye movements were monitored via a Fourward Technologies (Buena Vista, VA) Generation-V dual-Purkinje-image eyetracker. The eyetracker has a resolution of 10 min of arc (~½ character), and the signal from the eyetracker was sampled every millisecond by a 486 computer. The passages were displayed on an NEC (Rancho Cordova, CA) MultiSync 4FG color monitor that was interfaced to the computer. The passages ranged from five to seven lines of text and used double-spacing. They were presented in the center portion of the screen—the text began three lines down from the top of the screen, and each line was limited to the central 60 characters of an 80-character line. Participants were seated at a viewing distance of approximately 56 cm from the monitor, and 3 characters subtended 1° of visual angle. Although viewing was binocular, eye movements were recorded from the right eye.

Procedure. When participants arrived for the experiment, they were given a consent form that described the experimental procedure. A bite bar (to minimize head movements) was then prepared for use during the experiment. Participants were instructed to read each passage on the monitor while their eye movements were recorded. They were told that each passage could be read as a short story and that there would be yes–no comprehension questions after half of the passages. They were told that the questions were there to ensure they were reading and that, although there were questions, they should not read to memorize the text but rather to understand it, as if they were reading an interesting article in a magazine.

The experiment involved initial calibration of the eyetracking system, reading of 3 practice passages, recalibration, and then reading of the 48 experimental passages. No filler passages were included. The initial calibration generally required about 5 min. The calibration display appeared before every passage and involved a series of calibration points that extended over the maximal horizontal and vertical range in which a passage could be presented. During the calibration display, the calculated position of the eye was represented by a red dot. In this way, the experimenter could check the accuracy of the calibration by having participants directly fixate different points and assessing whether the real and the computed eye position were aligned. In addition to calibrating before the presentation of practice and experimental blocks of materials, the experimenter could calibrate between any passage when it was deemed necessary.

Each trial began with the calibration display. After the calibration was checked, the participant was asked to fixate the top-left calibration point, which corresponded to the first character of text of the upcoming passage.

[1] More recently, Zeno, Ivens, Hillard, and Duvvuri (1995) have provided a word-frequency count based on a corpus of approximately 17 million word tokens. The corresponding average raw frequencies according to Zeno et al. for the ambiguous and HF control words were 70 and 68 per million, respectively. When weighted by an index of dispersion that reflects how widely a word is used in different subject areas, the average frequencies were 59 and 58 per million, respectively.

Once the participant was fixating there, the experimenter presented the passage of text by pressing a button. When the participant was finished reading the passage, he or she was instructed to first fixate a small box located below and to the right of the last word of the passage, then press a button to clear the screen. The calibration screen reappeared either immediately or, on half of the trials, after the participant had answered a yes–no comprehension question by pressing a *yes* or *no* response key. This procedure was repeated throughout the entire experimental session. Participants had no difficulty in answering the questions (96% correct, on average).

Results

The target region comprised the space before the ambiguous or control word and the word itself. Overall, the upper and lower cutoff values for single fixations were 750 and 100 ms, respectively. Data were excluded from the analyses for the following reasons: (a) There was a track loss on the line of text containing the target, (b) there was a blink on the target or the fixation preceding or following it, (c) the fixation on the target was either the first or last fixation on the line, or (d) the first fixation on the target was greater than 750 or less than 100 ms. Overall, 1.5% of the data were excluded for these reasons. The resulting data were analyzed over a number of *target* and *spillover* eye movement measures, occurring either on the target itself or after the initial target fixation(s) on another region of text, respectively. For each measure, a one-way analysis of variance (ANOVA) was performed both by participants (F_1) and by items (F_2), comparing the ambiguous condition with the overall, word-form (HF) control condition. The participant means across all measures are presented in Table 2, and the corresponding ANOVA results are presented in Table 3.

Target measures. Typically, most content words are fixated once; sometimes they are refixated or skipped. In this study, the probabilities for single fixation, immediate refixation, and skipping of the target were .70, .08, and .22, respectively. The standard eye movement measures for target-word processing include first fixation duration (FFD) and gaze duration (GD). FFD is the average duration of the first fixation on a word, irrespective of whether it is the only fixation on that word or one of two or more consecutive fixations. GD is the average sum of all consecutive fixations on a word before the reader moves to another word. Total fixation time (TT) incorporates GD plus any fixations returning to the target (e.g., those resulting from a regression). In this experiment, returning fixations occurred on about 15% of the trials. Crucially, for inclusion in TT, there must be at least one intervening fixation between when the eyes fixate (or skip) the target and when they return to it. For this reason, TT can functionally be considered at once a target and spillover measure, because later occurring, returning fixations are annexed to any principal first-pass fixation(s).

There was a significant effect of word type in FFD, GD, and TT measures, with longer fixations for ambiguous than for control words. The single fixation duration (SFD) measure has been used more recently in eye movement data analysis (Rayner, Sereno, & Raney, 1996; Sereno, 1992) and represents only those cases when the target was fixated exactly once. The pattern of results was similar for SFD, although the effect was statistically marginal.

Spillover measures. Spillover measures are used to determine whether processing difficulty continues after the initial fixation(s) on the target by sampling fixation time at different temporal and spatial offsets relative to the target. Although they provide a more complete record of processing, they occur temporally downstream from the target and do not reflect its immediate processing. One such measure is the duration of the fixation that occurred immediately after the initial target fixation(s) but on a word other than the target (T+1). Thus, T+1 represents the fixation that temporally followed the target and, in most cases, spatially followed the target. A second spillover measure is the time on the next two words following the target (+2W). The +2W measure is functionally equivalent to GD on a target region that encompasses two words. The T+1 and +2W measures were used in Sereno et al. (1992) and are specifically reported here for purposes of comparison. For both spillover measures, no significant differences between ambiguous and control conditions were found (all Fs < 1).

Table 2
Mean Fixation Durations (in Milliseconds) Across Target and Spillover Measures for Ambiguous and Word-Form (HF) Control Words in Experiment 1

Measure	A	HF	A − HF
Target			
FFD	275	262	13*
SFD	277	266	11‡
GD	292	275	17*
TT	329	297	32**
Spillover			
T+1	245	249	−4†
+2W	319	322	−3†

Note. A = ambiguous; HF = high frequency; FFD = first fixation duration; SFD = single fixation duration; GD = gaze duration; TT = total fixation time; T+1 = next forward-going fixation; +2W = fixation time on the next two words.
† $p > .20$. ‡ $.10 < p < .05$. * $p < .05$. ** $p < .01$.

Table 3
Analyses of Variance (ANOVAs) by Participants (F_1) and by Items (F_2) on Target Measures in Experiment 1

Measure	*df*	*F*	*MSE*	*p*
FFD				
F_1	1, 17	7.55	190	<.05
F_2	1, 47	6.11	884	<.05
SFD				
F_1	1, 17	4.01	272	.061
F_2	1, 47	2.65	996	.111
GD				
F_1	1, 17	5.85	442	<.05
F_2	1, 47	7.03	1,222	<.05
TT				
F_1	1, 17	13.31	714	<.01
F_2	1, 47	7.20	3,813	<.05

Note. One-way ANOVAs on spillover measures did not reach significance. FFD = first fixation duration; SFD = single fixation duration; GD = gaze duration; TT = total fixation time.

Discussion

Experiment 1 tested whether the SBE found in Kambe et al. (2001) could be attenuated when passages using mixed contexts

(i.e., ones supporting first the dominant, then the subordinate meaning of an ambiguous target) were removed. The results, however, showed confirmation of the SBE in target measures—readers fixated longer on the ambiguous than on the word-form (HF) controls (significant in FFD, GD and TT; marginal in SFD). However, no differences were found in spillover measures (T+1, +2W). Although the average fixation time was about 10–15 ms shorter in this study than in Kambe et al., the pattern of results in both target and spillover measures is roughly comparable to that in their consistent/before condition.[2] The results also confirm Sereno et al.'s (1992) findings of longer target fixations for subordinate-biased ambiguous words than for HF, word-form controls. However, Sereno et al. (1992) additionally reported longer fixations in TT and spillover measures, findings that were not replicated here. One explanation is that the current experiment's longer contexts, containing both global and local biasing qualities, were stronger than the initial part of a single sentence used in Sereno et al. (1992) and, consequently, provided better conditions for proficient postlexical integration, if not lexical access itself.

Experiment 2

Experiment 2 examined the SBE in relation to the type of control word used. As mentioned previously, most ambiguity studies have used a control word matched to the overall word-form frequency of the ambiguous word. Sereno et al. (1992) suggested that a more appropriate control word might be one matched to the contextually instantiated meaning. When biased ambiguous words are presented in subordinate-biasing contexts, such meaning-matched controls would be of considerably lower frequency than form-matched controls and, hence, would attract longer fixations, reducing the SBE. Experiment 2 tested this by substituting semantically similar meaning-matched (LF) controls for the form-matched (HF) ones used in Experiment 1. Fixation-time measures for ambiguous and meaning-matched (LF) control words were compared.

Method

Participants. Eighteen members of the University of Massachusetts at Amherst community participated in the experiment and either received experimental course credit or were paid ($8/hr). The average age of participants was 25 years (range: 20–42); 12 were female, and 6 were male. All had normal or corrected-to-normal vision and were naive concerning the purpose of the experiment. None had participated in Experiment 1.

Materials. The materials were identical to those used in Experiment 1, except the original word-form (HF) controls were replaced with a different set of word-meaning (LF) controls (see the Appendix). In this experiment, each ambiguous word was paired with an unambiguous word matched in word length, frequency of the contextually instantiated subordinate meaning, and semantic fit within the passage. The average length was 4.96 characters for ambiguous words and 4.92 characters for control words. The average frequency of the control words was 5 per million (Francis & Kučera, 1982), roughly equivalent to the average frequency of the subordinate meaning of the ambiguous words.[3] That is, the mathematical product of the average frequency for ambiguous words (65 per million) and the estimated average component meaning of the subordinate meaning (6%) yields an average goal word frequency of 4 per million. Thus, the actual value of 5 per million was very close to the desired value of 4 per million.

Design. The design was similar to that of Experiment 1, with the exception that the control condition comprised a different set of words.

Apparatus. The apparatus was identical to that of Experiment 1.

Procedure. The procedure was identical to that of Experiment 1. As in the first experiment, participants experienced no difficulty in correctly answering the questions (94% correct, on average).

Results

The same criteria from Experiment 1 for inclusion as a target-region fixation were used. A total of 2.8% of data were excluded from the analyses in this experiment. The same target and spillover measures were used, and one-way ANOVAs (F_1 and F_2) were performed on the data, comparing the ambiguous with the word-meaning (LF) control condition. The participant means across all measures are presented in Table 4, and the corresponding ANOVA results are presented in Table 5.

Target measures. The probabilities for single fixation, immediate refixation, and skipping of the target were .70, .12, and .18, respectively. Returning fixations (e.g., from a regression) occurred on about 19% of the trials. There was a significant effect of word type in all target measures—FFD, SFD, GD, and TT—with shorter fixations for ambiguous than for control words. The only exception was a marginal effect in GD by items.

Spillover measures. For both spillover measures, T+1 and +2W, no significant differences between ambiguous and control conditions were found: for T+1, $F_1(1, 17) = 1.56$, $MSE = 256$, $p > .20$, and $F_2 < 1$; for +2W, $F_1(1, 17) = 1.12$, $MSE = 638$, $p > .30$, and $F_2 < 1$.

Combined data. The GD data from Experiments 1 and 2 were combined into a mixed ANOVA using word type (ambiguous vs. control) as the within-group factor and participant group (Experiment 1 vs. Experiment 2) as the between-groups factor. The effect of group was significant in the items analysis, $F_2(1, 94) = 9.53$, $MSE = 1{,}633$, $p < .01$, but not in the participants analysis ($F_1 < 1$). More important, there was a significant Word Type × Participant Group interaction, $F_1(1, 34) = 13.21$, $MSE = 502$, $p < .001$; $F_2(1, 94) = 10.43$, $MSE = 1{,}424$, $p < .01$. Follow-up, one-factor ANOVAs were computed separately for ambiguous and control words. The ambiguous words were identical across experiment, whereas the control words varied (HF or LF). No difference was found between ambiguous words in Experiment 1 and Experiment 2 (292 vs. 288 ms, respectively [$Fs < 1$]). However, the difference between control words in Experiment 1 (HF; 275 ms) and Experiment 2 (LF; 310 ms) was reliable, $F_1(1, 34) = 4.60$, $MSE = 2{,}375$, $p < .05$; $F_2(1, 94) = 21.57$, $MSE = 1{,}409$, $p < .001$.

Discussion

Experiment 2 tested whether the SBE could be eliminated by using a different control condition. A control word matched to the frequency of the ambiguous word's instantiated subordinate meaning is, in effect, an LF word, whereas the standard control,

[2] Exact comparisons cannot be made because Kambe et al.'s (2001) statistical tests were performed on means that included other conditions. Also, they did not report FFD or SFD, and their posttarget region included 2–5 words.

[3] The corresponding Zeno et al. (1995) average raw frequency for LF controls was 6 per million; when weighted by an index of dispersion, the average frequency was 4 per million.

Table 4
Mean Fixation Durations (in Milliseconds) Across Target and Spillover Measures for Ambiguous and Word-Meaning (LF) Control Words in Experiment 2

Measure	A	LF	A − LF
Target			
FFD	263	283	−20**
SFD	265	291	−26***
GD	288	310	−22*
TT	332	368	−36**
Spillover			
T+1	252	245	7†
+2W	348	339	9†

Note. A = ambiguous; LF = low frequency; FFD = first fixation duration; SFD = single fixation duration; GD = gaze duration; TT = total fixation time; T+1 = next forward-going fixation; +2W = fixation time on the next two words.
† $p > .20$. * $p < .05$. ** $p < .01$. *** $p < .001$.

matched to the frequency of the ambiguous word as a whole, is an HF word. Using the LF control, the results of this experiment showed a reverse SBE in target measures (ambiguous < control) and no SBE in spillover measures (ambiguous = control). Previously, Sereno et al. (1992) had used meaning-matched (LF) controls and found no SBE in the target measure of GD (ambiguous = control); however, they did find evidence for the SBE in both TT as well as spillover measures comparable to T+1 and +2W (ambiguous > control).

Experiment 3

The purpose of Experiment 3 was to manipulate word type—ambiguous, HF control, and LF control—within the context of a single experiment. Although the GD data from the first two experiments were combined in a between-groups comparison, there were several advantages to conducting such an experiment. First, word type could be treated as a within-group factor. Second, the experiment would serve as an independent replication of both Experiment 1 and Experiment 2. Finally, in addition to examining the SBE with respect to either control word, we could verify the word-frequency effect itself by directly comparing fixation times on HF and LF unambiguous control words.

For an experiment with three levels of word type in sets of passages constructed for only two levels to be implemented, certain changes to the materials were required. For each set of two passages, a third one was created to accommodate the use of both controls. In addition, we shortened the original passages by removing the two semantically empty sentences between the first and last sentences, which contained the global and local contexts, respectively (see Table 1). If results similar to those of the first two experiments were obtained with these modified materials, this would serve to strengthen the interpretation of the pattern of data.

Method

Participants. Forty-five members of the University of Massachusetts at Amherst community participated in the experiment and received either experimental course credit or money ($8/hr). An additional 7 participants were tested whose data were not included for the following reasons: They had high data loss as a result of eyetracking problems ($n = 4$), they were dyslexic ($n = 2$), or English was not their first language ($n = 1$). The average age of participants was 25 years (range: 18–45); 27 were female, and 18 were male. All had normal or corrected-to-normal vision and were naive concerning the purpose of the experiment. None had participated in either Experiments 1 or 2.

Materials. The same 24 ambiguous targets along with the form-matched (HF) controls from Experiment 1 and the meaning-matched (LF) controls from Experiment 2 were used in this experiment. To accommodate both controls within the same experiment, we created a third passage for each set of three words (ambiguous, HF, and LF) so that each participant could be presented with each word in a different passage. Thus, there was a total of 72 passages—the 48 used in Experiments 1 and 2 and 24 new ones.

We shortened the 48 passages from Kambe et al. (2001) by removing the two filler sentences that appeared between the first, global context and last, local context sentences (see Table 1). There were several reasons for doing this. A number of participants from Experiments 1 and 2 had commented that the passages were somewhat difficult or confusing in that the middle part did not seem relevant to the "story" that opened and closed the passage. It was also noted in scoring the data that some participants, after making their way through the passage, would go back and reread the first sentence. Kambe et al. had manipulated the consistency of the global and local contexts; the filler sentences helped camouflage any contextual switching. However, no such switching was present in the current study. For these reasons, the filler sentences seemed extraneous if not confusing, and they were removed. As a result, we made a handful of additional minor changes to a few of the passages to maintain textual coherence. A full list of the materials appears in the Appendix.

Design. Three sets of 72 passages were devised. In Set 1, ambiguous words appeared in the A versions, word-form (HF) controls appeared in the B versions, and word-meaning (LF) controls appeared in the C versions. In Set 2, the A, B, and C versions contained HF, LF, and ambiguous words, respectively. In Set 3, the A, B, and C versions contained LF, ambiguous, and HF words, respectively. One third of the participants ($n = 15$) read each of the three sets of passages. In this way, each participant was presented with all ambiguous, HF, and LF targets, each in a different passage. With three experimental conditions, there was a possible total of 24 data points per participant per condition.

Apparatus. The apparatus was identical to that of Experiments 1 and 2.

Procedure. The procedure was identical to that of the first two experiments except that there were 72 experimental passages. As before, par-

Table 5
Analyses of Variance (ANOVAs) by Participants (F_1) and by Items (F_2) on Target Measures in Experiment 2

Measure	*df*	*F*	*MSE*	*p*
FFD				
F_1	1, 17	14.38	266	<.01
F_2	1, 47	8.12	884	<.05
SFD				
F_1	1, 17	23.48	253	<.001
F_2	1, 47	9.33	1,713	<.01
GD				
F_1	1, 17	7.36	562	<.05
F_2	1, 47	3.90	1,626	.054
TT				
F_1	1, 17	9.80	1,227	<.01
F_2	1, 47	4.60	4,935	<.05

Note. One-way ANOVAs on spillover measures did not reach significance. FFD = first fixation duration; SFD = single fixation duration; GD = gaze duration; TT = total fixation time.

ticipants experienced no difficulty in answering the comprehension questions (94% correct, on average).

Results

The same criteria as in Experiments 1 and 2 for data inclusion were used. A total of 3.1% of data were excluded from the analyses in this experiment. A one-way ANOVA was performed for each target and spillover measure, both by participants and by items, comparing ambiguous, word-form (HF), and word-meaning (LF) conditions. Significant main effects were followed up with contrasts that tested the three comparisons of interest—ambiguous versus HF, ambiguous versus LF, and LF versus HF. The participant means across all measures are presented in Table 6, the corresponding ANOVA results are presented in Table 7, and the results of follow-up contrasts are presented in Table 8.

Target measures. The probabilities for single fixation, immediate refixation, and skipping of the target were .71, .08, and .21, respectively. Fixations returning to the target occurred on about 13% of the trials. There was a significant effect of word type in all target measures. Follow-up contrasts showed that all means differed from each other. The overall pattern of data was consistent across all measures, with the ambiguous-word condition situated between the longer LF and the shorter HF conditions. We examined the three contrasts across the four target measures in turn. All contrasts were significant. First, ambiguous words were fixated longer than HF controls. Second, ambiguous words were fixated shorter than LF controls. Third, LF controls were fixated longer than HF controls.

Spillover measures. We also carried out analyses for the two spillover measures. First, there was a main effect of target-word type only in the +2W measure, though it was marginal for the T+1 measure. Second, we performed the three follow-up contrasts for each measure. The pattern of results over all contrasts indicated that the main effects from the one-way ANOVAs (significant or marginal) were principally attributable to differences between the target LF and HF control conditions. The effect of target-word frequency was significant, with fixations following the LF controls significantly longer than those following the HF controls. The majority of remaining contrasts were at best statistically marginal. In the +2W measure, as with the target data, the ambiguous condition was positioned between the two control conditions. In the T+1 measure, the ambiguous condition was similar to the LF condition.

Table 7
Analyses of Variance (ANOVAs) by Participants (F_1) and by Items (F_2) on Target and Spillover Measures in Experiment 3

Measure	*df*	*F*	*MSE*	*p*
FFD				
F_1	2, 88	14.76	198	<.001
F_2	2, 142	11.26	519	<.001
SFD				
F_1	2, 88	14.36	231	<.001
F_2	2, 142	12.44	568	<.001
GD				
F_1	2, 88	26.92	245	<.001
F_2	2, 142	13.82	891	<.001
TT				
F_1	2, 88	31.42	558	<.001
F_2	2, 142	12.76	2,301	<.001
T+1				
F_1	2, 88	2.42	263	.095
F_2	2, 142	1.98	532	.143
+2W				
F_1	2, 88	7.26	970	<.01
F_2	2, 142	5.55	1,602	<.01

Note. FFD = first fixation duration; SFD = single fixation duration; GD = gaze duration; TT = total fixation time; T+1 = next forward-going fixation; +2W = fixation time on the next two words.

Norming data. The finding of shorter fixation times on ambiguous than on LF words is consistent with Experiment 2. To further explore this reverse SBE effect, we conducted two norming studies in an attempt to find out whether there were systematic plausibility differences across conditions. In both norming studies, three lists of stimuli were prepared, as described in the *Design* section above. However, only one of the three conditions (A, B, or C) for each item (1–24) was used, because the three targets (e.g., *notes*, *songs*, *tunes*) were often related. In the first norming study, in addition to 24 experimental passages, 8 filler items similar in structure but containing an anomalous target were included. For each passage, the target word was underlined. Fifteen participants

Table 6
Mean Fixation Durations (in Milliseconds) Across Target and Spillover Measures for Ambiguous, Word-Form (HF), and Word-Meaning (LF) Control Words in Experiment 3

Measure	A	HF	LF	A − HF	A − LF	LF − HF
Target						
FFD	264	256	272	8**	−8*	16***
SFD	268	258	275	10**	−7*	17***
GD	280	268	292	12***	−12***	24***
TT	308	286	326	22***	−18***	40***
Spillover						
T+1	254	248	255	6‡	−1†	7*
+2W	341	329	354	12‡	−13*	25***

Note. A = ambiguous; HF = high frequency; LF = low frequency; FFD = first fixation duration; SFD = single fixation duration; GD = gaze duration; TT = total fixation time; T+1 = next forward-going fixation; +2W = fixation time on the next two words.
† $p > .20$. ‡ $.10 < p < .05$. * $p < .05$. ** $p < .01$. *** $p < .001$.

Table 8
Follow-Up Contrasts by Participants (F_1) and by Items (F_2) on Target and Spillover Measures in Experiment 3

	A vs. HF		A vs. LF		LF vs. HF	
Measure	*F*	*p*	*F*	*p*	*F*	*p*
Target						
FFD						
F_1	8.15	<.01	6.64	<.05	29.50	<.001
F_2	5.52	<.05	5.74	<.05	22.51	<.001
SFD						
F_1	10.36	<.01	4.42	<.05	28.31	<.001
F_2	7.38	<.01	5.13	<.05	24.81	<.001
GD						
F_1	13.07	<.001	13.86	<.001	53.84	<.001
F_2	5.82	<.05	8.06	<.01	27.58	<.001
TT						
F_1	18.19	<.001	13.35	<.001	62.71	<.001
F_2	7.90	<.01	4.97	<.05	25.40	<.001
Spillover						
T+1						
F_1	2.77	.099	<1	*ns*	4.31	<.05
F_2	1.84	.177	<1	*ns*	3.75	.055
+2W						
F_1	3.27	.074	4.00	<.05	14.50	<.001
F_2	2.24	.137	3.34	.07	11.06	<.01

Note. A = ambiguous; HF = high frequency; LF = low frequency; FFD = first fixation duration; SFD = single fixation duration; GD = gaze duration; TT = total fixation time; T+1 = next forward-going fixation; +2W = fixation time on the next two words.

(5 in each counterbalancing condition), none of whom had participated in any of the prior experiments, read each passage and were asked to rate on a 5-point scale how well the underlined word fit into the passage (1 = *not at all*; 5 = *very well*). For the experimental items, the average ratings for ambiguous, HF, and LF words were 4.1, 4.1, and 3.8, respectively. These differences were not significant ($F < 1$). Thus, target words from the three conditions were judged to fit equally well into their respective passages.

The second norming study was a cloze task in which the 24 experimental passages were presented up to, but not including, the target word. Twenty-one participants (7 in each counterbalancing condition), none of whom had participated in any of the prior experiments or the first norming study, were asked to write down the first word that came to mind as a continuation of the passage. The percentages of responses corresponding to the ambiguous, HF, and LF targets were 7.94%, 5.75%, and 0.99%, respectively. Although these differences were highly significant, $F(2, 40) = 15.45$, $MSE = 17$, $p < .001$, prior research has demonstrated that such low predictability values typically have little influence on eye fixation times (Hyönä, 1993; Rayner & Well, 1996). More recently, however, Frisson, Rayner, and Pickering (2005) did obtain differences for words with predictability values on the lower end of the scale. Therefore, target words that were generated three or more times across all participants were identified: six ambiguous words (*notes*, *bank*, *habit*, *horn*, *pipes*, and *cabinet*) and two HF words (*floor* and *puppy*). Because the reverse SBE is expressed as a (negative) difference between ambiguous and LF words, the six ambiguous words along with their matched HF and LF controls were removed from the items analysis for GD (the two HF items and their matched ambiguous and LF controls were left in). As in the full items analysis reported above, there was a significant main effect of word type in GD, $F_2(2, 106) = 12.34$, $MSE = 1{,}017$, $p < .001$. Follow-up contrasts were also similar to the full items analysis, with longer fixation times on LF than on both ambiguous, $F_2(1, 106) = 8.16$, $p < .01$, and HF words, $F_2(1, 106) = 24.42$, $p < .001$, and longer fixation times on ambiguous than on HF words, $F_2(1, 106) = 4.37$, $p < .05$. Thus, removing the more predictable ambiguous words (and corresponding controls) from the analysis did not affect the pattern of results.

Discussion

Experiment 3 tested for the presence of the SBE in simultaneous relationship to both a word-form (HF) and a word-meaning (LF) control. While serving as a replication of the first two experiments, it also allowed for word frequency effects to be examined. The stimulus materials from the earlier experiments had been modified for Experiment 3—the original passages were shortened to make them more cohesive, and one-third of the passages were new. These changes addressed whether the earlier effects would generalize to a different set of materials.

The results of Experiment 3, in general, confirmed the findings from Experiments 1 and 2. The pattern of target data in FFD, SFD, GD, and TT measures clearly replicated what was found in the earlier experiments. There was an SBE for ambiguous versus form-matched (HF) controls (with longer fixations on ambiguous words) as well as a reverse SBE for ambiguous versus meaning-matched (LF) controls (with shorter fixations on ambiguous words). In addition, the reverse SBE persisted even when more predictable ambiguous items were removed from the analyses. In terms of the spillover data (T+1, +2W), the picture was less definitive. In Experiments 1 and 2, there was no evidence of any differences between ambiguous and control (HF or LF) conditions. In the current experiment, although none of the differences between ambiguous and control conditions in either spillover measure reached significance in participants and items analyses, it may still be possible to argue for weak effects in the +2W measure. Here, the pattern of data mimicked what was found in target measures—fixation time following the ambiguous word split the difference between the slower LF and faster HF conditions. It is important to note that the spillover measures of T+1 and +2W are comparable in duration to FFD and TT, respectively, yet the effect size is roughly half that of the target measures. As in Experiments 1 and 2, the overall lack of spillover effects (or ones that hint at an echo of target effects) contradicts the earlier findings from Sereno et al. (1992). The most plausible account for this discrepancy seems to rest with the use of stronger contexts in the present study.

Contrasts comparing LF and HF controls showed highly significant word-frequency effects across all target measures, even though the frequency disparity was moderate in comparison with other studies (e.g., Sereno & Rayner, 2000). The effects of word frequency in spillover measures, unlike the ambiguity effects, were quite reliable and consistent with previous research (e.g., Henderson & Ferreira, 1990; Inhoff & Rayner, 1986; Rayner & Duffy, 1986; Sereno et al., 1992).

General Discussion

The present experiments examined the role of context and the control word in assessing ambiguous word processing. Recent investigations of lexical ambiguity have focused on the SBE—when context supports the subordinate meaning of a biased ambiguous word, reading time on the ambiguous word is longer than it is on an unambiguous control word. One issue of debate is whether an appropriate context can attenuate the SBE. Eye movement studies that have used longer contexts have also tended to manipulate the consistency of the context within the same experimental design. In such cases, readers receive information biasing both dominant and subordinate meanings of an ambiguous word within the same context. Experiment 1 addressed this concern by using consistent contexts—taken from one of the conditions of Kambe et al. (2001)—that only biased the subordinate meaning. The results from Experiment 1, however, confirmed the existence of the SBE, showing longer fixations on ambiguous than on control targets.

Another issue in ambiguity studies concerns the nature of the control word. Typically, the control word is chosen to match the ambiguous word's overall word-form frequency, even under the circumstance of prior context instantiating the ambiguous word's subordinate meaning. Sereno et al. (1992) chose two control words for this condition—one matched to the ambiguous word's form (an HF word) and one matched to its subordinate meaning (an LF word). They found that reading time on the ambiguous word was no different from that on the LF control, and both were longer than that on the HF control. In Experiment 2 of the present investigation, the original form-matched, HF controls used in Experiment 1 were replaced with meaning-matched, LF controls. The results of Experiment 2, however, did not confirm the earlier findings of Sereno et al. (1992). Reading time was shorter on ambiguous words than on LF controls, a reverse SBE.

Experiment 3 incorporated the first two experiments within a single design. Additional passages were constructed to accommodate both HF and LF controls, and the original passages were shortened to increase their coherence. The results replicated the pattern of effects observed in Experiments 1 and 2, with longer times on ambiguous than on HF controls (SBEs) and shorter times on ambiguous than on LF controls (reverse SBEs). Although a comparison between Experiments 1 and 2 had also demonstrated this pattern, Experiment 3 extended these findings by replicating them within a single group of participants over a set of materials that had been substantially changed.

In addition to the target measures of FFD, SFD, GD, and TT, two measures of processing spillover, T+1 and +2W, were also examined. For the most part, the pattern of spillover data showed no reliable differences between ambiguous and control conditions across all three experiments. There was some indication in Experiment 3 of a minor carryover of target effects in the +2W measure. In contrast, Sereno et al. (1992) found additional reading time for the ambiguous condition in spillover measures. The lack of spillover effects for ambiguous versus HF controls (Experiments 1 and 3) and, in particular, for ambiguous versus LF controls (Experiments 2 and 3) seems to demonstrate that readers encounter no more difficulty in integrating the meaning of one condition than another. It is also possible that one condition may be more difficult to integrate but that competing influences counterbalance this effect. However, the former seems more likely, because contexts in the current series of experiments were both longer and more biasing than those used by Sereno et al. (1992). Such contexts effectively increase not only the time but the depth of processing, resulting in a richer discourse representation and leading to more efficient integration.

Experiment 3 additionally investigated word frequency in that the two unambiguous controls (HF and LF) differed precisely in this respect. Significant word-frequency effects were found across all target measures, a pattern consistent with numerous eye movement studies (for a review, see Rayner, 1998). A frequency effect, especially in FFD, is considered to reflect immediate processing differences, and its presence has generally been interpreted as a marker of successful lexical access (Balota, 1990; Sereno & Rayner, 2003). The frequency effect obtained here occurred in contextually biasing conditions in which such effects should be reduced. That is, numerous reaction-time studies (for a review, see Neely, 1991) as well as a recent electrophysiological study (Sereno, Brewer, & O'Donnell, 2003) have provided evidence for a Frequency × Context interaction whereby LF words are facilitated more by a biasing context (but cf. Rayner, Ashby, Pollatsek, & Reichle, 2004).

Experiment 3 demonstrated significant frequency effects in spillover measures as well, a finding consistent with previous research. Accounting for such effects, however, has proven more difficult. The temporal locus of frequency effects over a short succession of fixations has generated different interpretations about the time course of lexical processing, and it plays an important role in explaining eye movement control during reading (Henderson & Ferreira, 1990; Pollatsek & Rayner, 1990; Rayner, Sereno, Morris, Schmauder, & Clifton, 1989; Reichle, Rayner, & Pollatsek, 2003; Sereno, 1992). Henderson and Ferreira (1990), for example, suggested that spillover effects arise from the reduced parafoveal processing that accompanies conditions of high foveal load. For this reason, longer posttarget fixations are observed following an LF than following an HF word. Another explanation of frequency spillover effects involves meaning integration. Rayner et al. (1989) showed that it was not simply the case that LF adjectives were harder to integrate per se than HF adjectives with a subsequent noun. Because frequency differences on the target adjective were not correlated with spillover differences on the noun, the authors suggested that spillover effects were instead attributable to higher level integration functions such as conceptual combination.

The pattern of results across the three experiments showed that reading times on biased ambiguous words in subordinate-biasing contexts were longer than those on form-matched (HF) controls but shorter than those on meaning-matched (LF) controls. These differences (ambiguous vs. HF, ambiguous vs. LF, LF vs. HF) were significant in target measures. However, because the magnitude of effects was considerably smaller in spillover than in target measures, only the frequency difference reached significance here. The results are compatible with the reordered access model, in which both meaning frequency and prior context can influence access procedures. A strong interactive model would predict no difference in the processing of ambiguous and LF words. Any modular account, in which selection of the appropriate meaning occurs during a postlexical integration stage of processing, would

predict increased difficulty minimally in spillover if not in target measures.

An ambiguous word obviously relies on prior context for the reader to select the appropriate meaning. An unambiguous word, in contrast, does not have the same dependent relationship with context. It could be argued that to equitably compare an ambiguous with an unambiguous (HF or LF control) word, the prior context should be strongly biasing. Although contexts in the current study may still not have achieved the strength necessary for unimpeded meaning resolution, they came closer than those provided, for example, in Sereno et al. (1992). It could also be that the type of ambiguous word and its functional link to context—a biased ambiguous word with context instantiating the weak, subordinate meaning—may represent a special case. That is, such a word is at once both an HF word in terms of its word form and an LF word in terms of its meaning. It is not a matter of debate that a word's form and meaning both play a role in lexical access processes (e.g., Pickering & Frisson, 2001). In terms of word form, an ambiguous word should be processed no faster than an HF control but faster than an LF control. In terms of word meaning, it should be processed more slowly than an HF control but no slower than an LF control. The relative input and timing of form and meaning information during lexical access procedures should consequently determine an ambiguous word's fixation-time profile, a proposal consistent with the reordered access account.

Perhaps the most interesting result from the present study is the presence of a reverse SBE, with shorter reading times on ambiguous words than on LF controls. This effect appears reliable in that it occurred in both Experiments 2 and 3. The interpretation of this effect, however, is less certain. One possibility for why ambiguous words are processed faster than LF controls is that this represents a "two are better than one" effect. There is a considerable literature on measuring and modeling behavioral responses to ambiguous versus unambiguous words (typically using lexical decision experiments, in which stimuli are presented in a "context-free" situation). In general, the results show that response time is shorter to ambiguous than to unambiguous words (e.g., Borowsky & Masson, 1996; Kawamoto, Farrar, & Kello, 1994; Jastrzembski, 1981; Joordens & Besner, 1994; Rubenstein, Lewis, & Rubenstein, 1971). Such an explanation, however, seems unlikely for several reasons. First, the unambiguous control words in these experiments were matched to an ambiguous word's word-form frequency (HF controls). Second, no distinction was made in these experiments between different types of ambiguous words in terms of the relative frequency of dominant and subordinate meanings. Eye movement experiments have consistently obtained differences in processing time as a function of whether an ambiguous word is biased or balanced. Finally, recent modeling work by Rodd, Gaskell, and Marslen-Wilson (2004) has shown a processing disadvantage for words with multiple unrelated compared with multiple related meanings. As with the reordered access model, Rodd et al. suggested that the effects were a result of competition among alternative meanings.

A second account for the presence of a reverse SBE may be that the LF controls did not fit into the passage as well as their ambiguous (or HF) counterparts. However, the two norming studies conducted did not provide much support for this hypothesis. In the first, the judgments of contextual fit between a passage and its target (ambiguous, HF, or LF) were statistically not significant across conditions (4.1, 4.1, and 3.8, respectively). In the second, the predictability values of targets, although quite low, differed significantly across ambiguous, HF, and LF conditions (7.94%, 5.75%, and 0.99%, respectively). When higher predictability items were removed from the analysis, however, the pattern of results did not change—the reverse SBE was still present. It is possible that there are subtle differences in contextual fit that are not captured by the norms that we used or that the offline, strategic nature of norming itself involves different integration mechanisms than those used during normal reading. Moreover, in the case of contextual-fit norming, it is likely that the target was judged not only with respect to the context which preceded it but also with respect to that which followed it, a process that first-pass target measures would not reflect. Clearly, further research is necessary to uncover the behavioral basis of the reverse SBE.

A final issue concerns the nature of contextual constraint. Although a context can be considered biasing in that it supports the meaning of a word, measurement of the degree of support is typically subjective in nature. Various attempts have been made to systematize judgments. Such methods include calculating cloze probability or feature overlap between context and target. The role of global versus local contexts has also been investigated. Variation in methodologies across studies, however, makes comparisons difficult. A recent computational approach involving the latent semantic analysis of large textual databases (e.g., McDonald & Shillcock, 2003a, 2003b; see also Frisson, et al., 2005) may provide future guidance. If context does exercise an early influence on word recognition, this creates a key role for semantic processes. Recent studies on the neurophysiology of lexical access indicate that a visual word is processed by temporal cortex within 120 ms, allowing early contact with semantic representations (e.g., Pulvermüller, Assadollahi, & Elbert, 2001; Sereno et al., 2003; Sereno, Rayner, & Posner, 1998). The onset of meaning processes at this early stage may blur the separation of lexical and semantic stores. The ambiguity question, set in neural terms, might then appropriately be stated as follows: How early can functionally higher brain regions influence lower ones? The resolution of this debate will depend on carefully controlled, temporally sophisticated empirical studies of reading in natural contexts.

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Appendix

Experimental Passages and Target Words for Experiment 3

There were 24 sets of passages. For each set, there were three possible target words (capitalized), listed from left to right as follows: ambiguous, word-form high-frequency (HF) control, and word-meaning low-frequency (LF) control. Each target could appear within any version (A, B, or C) of each set. Within each set, Versions A and B were modified from Kambe, Rayner, and Duffy's (2001) passages in that the two filler sentences that originally appeared between the global (first) and local (last) context sentences were removed. Version C of each set is new. Experiments 1 and 2 used the original, unmodified A and B passages from each set, which included the two filler sentences. In addition, Experiment 1 used only the ambiguous and word-form (HF) targets, whereas Experiment 2 used only the ambiguous and word-meaning (LF) targets.

1. TABLE PAPER GRAPH

(A) The data analyst needed several hours to complete all of her work. She spent hours organizing the information on the computer into a _____ that had to be faxed to the client before the presentation.

(B) Alex did not have a strong accounting background. The teacher pointed to a chart and explained all of the numbers in the _____ that the class would have to understand before the final exam.

(C) Suzy was asking her Aunt Jane about her first statistics class. "I remember," Aunt Jane said. "We always had to refer to a certain _____ in addition to the book." She laughed then continued, "By the end of the semester, it was almost worn out."

2. STORY FLOOR ATTIC

(A) Jody lived alone in a multilevel apartment complex. Jody's parents worried about her moving to a remote _____ of a recently restored building in the heart of the city.

(B) Mary preferred to take the elevator up to her office. Mary's office moved to an upper _____ of the incredibly tall building downtown last year.

(C) Sandra and Melanie were looking for an apartment in the old residential area of town. They wanted a place that had a view of trees. At last they found a place and moved to the highest _____ of an old mansion.

3. PLANT HOTEL DOCKS

(A) Amy worked the night shift in a building downtown. Yesterday, Amy's car broke down so she was late when she entered the _____ where she spent hours working with huge grinding machines that generated electricity.

(*Appendix continues*)

(B) Lucy worked at a loading bay when she was younger. She was happy that her days in the receiving office of the _____ where she had worked for years were over, and that she had a better life now.

(C) It was the tenth week of the strike and a quick settlement did not look likely. Some of the workers wanted to return to the _____ because they had spent all their savings. There would be another vote soon.

4. NOTES SONGS TUNES

(A) Sally loved to listen to classical music. She sat at her piano and played the opening series of _____ that she had prepared to perform at an upcoming concert.

(B) Jack saw the musicians auditioning in the concert hall. A cello player filled the room with several _____ that began to relax him as music filled the air.

(C) The choral group gathered for their weekly practice. The pieces for their next performance needed a lot of work. They struggled over the same set of _____ for most of the session without much success.

5. BALL TEST GALA

(A) Alice was thinking about hosting a formal party. Tonight, however, she knew she still had to attend the _____ that was being held in order to recognize individual growth and achievement where she worked.

(B) Kevin was uncomfortable in his rented tuxedo. He had arrived at the _____ that was required for all members of the ballroom dance class several hours ago and wanted to leave.

(C) When it came to social events, Mildred was terribly insecure. She attended a class called "How to Waltz Even if You Have 2 Left Feet." She was dreading the end-of-class _____ that everyone had to dress up for, but she knew she had to do it if she was ever going to improve her social skills.

6. BANK EDGE LEDGE

(A) The Phillips Co. was developing the waterfront area. They decided not to break ground too close to the river because the _____ of the incredibly large river was unstable and beginning to erode.

(B) Sammy hadn't been able to go camping at the lake in years. When he reached the water, he set up camp along the _____ of the beautiful river he loved to visit.

(C) The mother duck and her ducklings always moved together. If she paddled in one direction, they all followed. This time, she reached the shallows, then waded up onto the _____ and out of the water. Without hesitation, her ducklings did the same.

7. SPEAKER MACHINE RESISTOR

(A) Karen took a class on electrical design. An electrician even offered to explain how to fix a _____ that she was currently working on in her class.

(B) Andy taught a shop class at the local community college. He knew, however, that he had to stay and fix the wiring of a _____ he wanted to use for his class the next day.

(C) Eddie wanted to eavesdrop on his neighbors. Electronics was more than a hobby. He rigged together some microphones and a system including a _____ that would transmit the signals to a recording device.

8. BAND GOLD RUBY

(A) Lisa and John spent months looking for the perfect wedding ring. It wasn't until they entered Kay's Jewelry store that they saw the _____ that would make the perfect wedding ring for both of them.

(B) Mary Jo was surprised that the actor was wearing a wedding ring. She could not help but notice the elaborate engraving that decorated the _____ that he had on his ring finger.

(C) The annual crafts fair always attracted people from a wide area. This was because many of the vendors were gypsies who brought beautifully hand-crafted jewelry. My sister and I spent a while looking around and there was one piece that really caught our eye. We decided to buy the stunning _____ for our mother.

9. SCALES STONES GILLS

(A) Jeannie was excited about building her new aquarium. She decided to start by going to the fish section of the pet store to see if they had the type of _____ she wanted for the fish in her new aquarium.

(B) Billy was excited about his new job at the Marine Institute. When he arrived, he saw the display case containing the fossilized _____ that came from a large fish caught by a local man.

(C) Our pet piranha Pookie was looking sick. He did not come to the side of the tank to greet us and he had not eaten in two days. We noticed some green slime that was covering some of the _____ on one side. We would have to go get something to treat this.

10. WIRE CARD MEMO

(A) Paul was supposed to send a message to his sister. He had thought about what he wanted to say in the _____ for a long time, but never got around to sending it because he had been busy.

(B) Tom needed to send some money to his son in college. Since he had his checkbook, he went to the post office to send the _____ that he needed to get to his son before running errands.

(C) Agent Jackson had been out in the field for almost a year. He cleverly disguised his communication to the American Embassy by sending a _____ that was a dinner invitation addressed to Miss Strauss.

11. HABIT CROSS SHAWL

(A) Colleen was tormented by her sins. She knelt down in the church after putting on the _____ that all of the novices were required to wear within the convent walls.

(B) Although Peggy had a deep sense of faith she was troubled. Peggy decided to become a nun and wear a _____ in order to symbolize her devotion to religious life.

(C) The moon cast an eerie light as Sister Margaret hurried up the unlit road. She had heard tales about the vampire. Although she did not believe them, Sister Margaret was still cautious. So when she was out alone at night, she wore her _____ and carried a stake.

12. CORN WART CYST

(A) Bob had a doctor look at the painful growth on his foot. After examining Bob's toe, the doctor said that the _____ would have to be removed from his foot before it grew any bigger.

(B) The old woman complained that her feet hurt when she walked. Because it caused the old woman so much pain, the _____ was finally removed from her foot by a doctor.

(C) Scott's new shoes were too tight. He had been in agony all day at the office. When he got home he took off his shoes. There was a _____ on his right foot that was very red and extremely sensitive to touch.

13. LEGEND HARBOR RAVINE

(A) Marty looked at the street map when she realized that she was lost. Marty looked at her map in order to locate the _____ that would help her find the funeral home where the memorial service was going to be held.

(B) Joey wanted to draw a treasure map of Black Beard's Island. He lifted his pencil while he decided where to draw the _____ on his carefully constructed treasure map of Black Beard's island.

(C) The sun was setting fast and we had forgotten our flashlights. We frantically searched the map to figure out our location. We soon realized that the section of the map that showed the _____ had been torn off.

14. HORN TAIL SHIN

(A) Tom grew up on a goat farm in New Zealand. He was surprised when the young goat caught its _____ on the ancient wooden fence that bordered his house.

(B) Last week Joey helped his neighbor capture a wild bull. Later they went over to a sedated bull and wrapped a section of its _____ that had been injured earlier that day.

(C) Rocky, the rhinoceros at the Wild Animal Reserve, paced back and forth in his outdoor cage. It was sad to see him do the same thing over and over again. Rocky would walk to the water, turn, then rub his _____ against a boulder and return along the fence.

15. COACH CABIN SHACK

(A) Mark stood in line to enter the Old West theme park. Cowboys and horses came into view as he was finally allowed to enter the _____ that was crowded with people trying to get a tour of the old western town where they had just built a new blacksmith shop.

(B) On Sunday afternoons Debbie liked to watch old western movies. Today as she watched TV she saw that one of the windows in the _____ had an arrow sticking out of it.

(C) Falsely accused of the train robbery, the Grundy brothers were now fugitives with the Sheriff and U.S. Marshall in pursuit. They took temporary refuge in a dilapidated _____ that they happened to come across off the trail.

16. PIPES DRAIN HOSES

(A) Timothy saw the flood in the kitchen and called the landlord. He then waded over to the sink to look at the _____ with frustration before sitting on the counter to cry.

(B) Dale did most of the repairs on his new house. Before he could take a break, he needed to call a plumber to install the _____ that he wanted in the kitchen since he had been having trouble with the original hardware.

(C) Our friend Jeremy could fix anything. He came by to look at our washing machine. We moved it forward so that he could examine the _____ behind it that had stopped working. Fortunately, it would be a minor repair.

17. PORT BEER RUM

(A) Janice was supposed to write a critique of the local vineyard. She was quite nervous about going. As a result, she decided to drink a glass of _____ that she loved and then continued on her way.

(B) Fred and his friends wanted to go out for a drink to celebrate his new job. They decided to drink a bottle of _____ that they found locally, and relax for the evening at the beach.

(C) Simon poured his drink then took a deep puff off of his cigarette. The deal should have gone through by now. He leaned back in his chair and slowly exhaled. He reached for his glass, calmly sipped some _____ and waited for the phone to ring.

18. CABINET ANALYST BROKER

(A) The governor had a big crisis on his hands. He called an emergency lunch time meeting that included his _____ in the conference room, for a debriefing and planning session.

(B) The President needed to meet with his advisors as soon as possible. Finally, he called for a debriefing session with his _____ in a private room where they could go to work.

(C) Making financial projections for the University required confidential face-to-face advice from experts. The University Provost decided to meet with his _____ to consider the budgetary plans in detail.

19. PEN ZOO SHED

(A) Mark and his father developed a portable structure for holding animals. Since it was originally intended for smaller animals, the _____ had to be completely rebuilt with new materials and larger dimensions.

(B) Lois inspected animal habitats for the Humane Society in Europe. Because it was too dirty for the animals to live in, the _____ was finally closed down by the Humane Society.

(C) Nancy loved animals. She had worked as a vet but decided to take her skills into the field. She would scout the local terrain for wounded animals. She would treat their injuries and take them to a special _____ that was designed to rehabilitate them to living in the wild again.

(*Appendix continues*)

20. DIAMOND PARKWAY DUGOUT

(A) Billy and his friends had plans to play baseball. Billy had his bat and glove with him when he arrived at the _____ where everyone would meet for a game later that day.

(B) Tony was the best catcher in his baseball league. He was wearing his team uniform when he arrived at the _____ and was surprised that the championship game he had been looking forward to had been cancelled.

(C) Russell had the best batting average in the league. He wanted to take some practice swings but he was waiting for his friend Cameron to arrive with his lucky bat. When Cameron showed up at the _____ without his bat, Russell was furious.

21. RACKET TENANT COLLIE

(A) Debbie and her husband were annoyed by the noise their neighbors made. Debbie decided to complain to her landlord about the _____ that always seemed to be around and was getting hard to ignore.

(B) Gloria liked hearing her neighbor play his guitar. College was over and the future seemed promising. She ignored the sound-sensitive people who complained about the _____ that was too loud for them to tolerate.

(C) Tessa normally was very tolerant of noise. However, all that evening there had been a great deal of disturbance from next door where the _____ was quickly becoming a serious cause for complaint.

22. MINT JAIL RINK

(A) Lori had an important interview with the Security Department. When Lori parked outside the _____ she checked her watch and saw that she was early for her interview.

(B) The officer checked the security system before leaving. The officer checked the locks on the outer door of the _____ very carefully before hurrying home to his wife.

(C) The guard was aware that a security breach of the building was more likely to occur at night. He often arrived for the late shift at the _____ well before the other guard was due to leave.

23. POKER SWORD SABRE

(A) Jack and his colleagues looked carefully at the murder weapon. Jack remained quiet as he carefully lifted the heavy _____ that was used to murder the rich couple.

(B) Lori enjoyed visiting the restored American colonial home. Lori would then stare at the heavy _____ that someone had carefully hung over the fireplace on display.

(C) Claire enjoyed collecting 17th century historical objects. The pride of her collection was an ornamental _____ from the reign of King Louis XIV of France.

24. BOXER PUPPY HUSKY

(A) Sam's pet died last week and he wanted a new companion. Sam decided to go to a kennel where he bought a _____ that he knew he would like to take home.

(B) After she was robbed, Mary decided to buy a dog. Mary wanted something to protect her so when she saw an ad for a _____ in the local paper, she bought it and immediately felt much safer.

(C) "I don't want a cat!" screamed Tara. Her parents were devastated. How could they have been mistaken? She liked dogs. They went out the next day and brought home a little _____ and hoped that their Tara would approve.

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