

TOP-DOWN EFFECTS ON MULTIPLE MEANING ACCESS WITHIN AND  
BETWEEN LANGUAGES

by

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## ABSTRACT

### TOP-DOWN EFFECTS ON MULTIPLE MEANING ACCESS WITHIN AND BETWEEN LANGUAGES

by

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This research investigates context effects on multiple meaning access during word recognition.

Previous monolingual word recognition research suggests that multiple meanings of homographs are temporarily activated. In disambiguating context, Reordered Access predicts multiple meaning activation, while Selective Access predicts single meaning activation. The difference arises from differences in their predictions for contextually-inappropriate meanings: Reordered Access predicts no context effects, and Selective Access predicts suppression due to context. Two eyetracking during listening experiments showed that top-down context both increased activation of the appropriate meaning of a homophone and decreased activation of the inappropriate meaning, however, multiple meanings were still activated. Thus, a strict form of neither Reordered Access or Selective Access can account for the present results.

Most previous research on context effects on homophone resolution assumed that participants fully engaged in the sentence processing tasks and fully understood the sentence contexts. However, if this assumption is invalid, the conclusions of previous studies may also be invalid. Two naming experiments investigated motivational effects (monetary compensation, supervision, feedback) on homograph meaning resolution. The results indicated that participant motivation increased overall task performance, but did not reliably affect homograph meaning activation.

Previous bilingual research has found that word-initial cohort competitors from multiple languages are activated, even in monolingual contexts. BIA+ and BIMOLA both account for multiple language activation, but differ in how context affects the nontarget language. BIA+ assumes that lexicons of multiple languages are integrated; context affects words in both languages simultaneously. In contrast, BIMOLA assumes that lexicons of multiple languages are stored in different language networks; context effects can be selective to one language. Three eyetracking-during-listening experiments showed that biasing context increased activation of the target language meaning, but did not affect the nontarget language activation. Thus, context effects on multiple language activation are language-selective, although multiple languages are activated, supporting the BIMOLA.

The present set of experiments demonstrated that regardless of surrounding context, multiple meanings and multiple languages are activated. Biasing context plays a role in modulating lexical activation, both facilitating appropriate meanings and inhibiting inappropriate meanings. However, context effects modulate meaning activation only in the target language.

## CHAPTER 1

### INTRODUCTION

In a normal day, we encounter thousands of words through reading, writing, speaking and listening. Comprehending and producing words may seem to be quick and effortless to us most of the time. In order to use and understand them, however, we must select them from a pool of tens of thousands of words from memory. Research has established that we can process words at great speed, accessing word meanings within approximately 200 ms of exposure (Gleason & Ratner, 1998; Marslen-Wilson, 1987). With such a small amount of processing time, one might question how we interpret a string of words as a meaningful expression so quickly and effortlessly.

I focus first on spoken word recognition because of its relevance to the current experimental paradigm, eyetracking during listening. In this task, participants' eye movements are recorded as they listen to spoken input and view objects on a screen. The pattern of eye movements is taken to reflect word recognition processes.

Although the numerous theories of spoken word recognition do not all agree on the processes involved, several processes are common: initial contact, activation, selection, and recognition (Frauenfelder & Tyler, 1987). Initial contact occurs when sensory input comes in contact with the lexicon. A set of matching word candidates is activated according to incremental processing of the spoken word input. After initial contact and activation, subsequent input is used to narrow down the candidates to select

one word that matches the input. Word recognition occurs when selection is accomplished, and the listener realizes which word was spoken.

One of several complications in the word recognition process is the existence of homophones in the spoken modality and homographs in the written modality. Homophones are words that share the same sound, but do not share meaning, for example *flour* and *flower*. Homographs are distinguished from homophones, as they are words that are spelled identically but have distinct meanings. Homographs and homophones are not mutually exclusive: many words may be homographs but not homophones, and vice versa. In reference to the modality-nonspecific theories of lexical ambiguity resolution, the terms *homograph* and *homophone* can be used interchangeably. However, in reference to models and paradigms specific to one or the other modality, the relevant term is used.

For homophones, the word recognition process cannot conclude simply by selecting the word that best matches the spoken input, since there are multiple words that share the same acoustic properties. Similarly, word recognition for bilinguals and multilinguals may be complicated by knowledge of words in more than one language. Just as in monolingual word recognition, incremental processing of spoken input may initially activate matching word candidates from multiple languages. For example, the English word *moon* shares initial phonemes with the Spanish word *muñeca*, which means *doll*. A Spanish-English bilingual may need to decide whether the meaning of *moon* or *doll* is intended upon hearing *moon*.

Normally, homophones do not produce comprehension difficulty because the context in which they are heard disambiguates the meaning, for example, *Alice smelled*

*the flower*. However, situations can occur in which the meaning is not disambiguated, as in *Alice saw the flower/flour*. Which meaning is activated depends on two key variables, frequency and context. The effects of frequency are the most straightforward: in neutral contexts, the more frequent, dominant meaning of an ambiguous word is activated more than less frequent, subordinate meanings (e.g., Simpson & Burgess, 1985; Simpson & Krueger, 1991).

The role of context in lexical ambiguity resolution is more controversial. The issue is whether context can control which meanings of a homophone are activated. Two major theories of lexical ambiguity resolution, Reordered Access and Selective Access, differ in their predictions of whether the access to multiple meanings of a word is independent of top-down context.

In Experiments 1 and 2, I investigated the effects of frequency and context on the pattern of activation of English homophones using eyetracking in the visual world. Eyetracking in the visual world provides detailed time course information about activation of meanings of a homophone. Activation of different meanings is measured using pictures depicting the alternative meanings. The results are discussed in reference to the two major theories of lexical ambiguity resolution.

Most previous research on context effects on homophone resolution assumed that participants fully engaged in the sentence processing tasks and fully understood the sentence contexts. However, if this assumption was not correct, the conclusions of previous studies must be reinterpreted. In order to test assumptions made in research on lexical ambiguity resolution, I investigated effects of motivation on the use of context during lexical ambiguity resolution. Two naming studies (Experiments 3 and 4) examined

within-language effects of motivation (monetary compensation, supervision, and feedback) on comprehension of subordinate biasing sentence contexts, in order to determine whether increased effort and performance affects homophone meaning activation.

In the last set of experiments, I investigated between-language word recognition for Spanish-English bilinguals. Using the visual world eyetracking paradigm, I explored whether top-down linguistic context can influence the pattern of language activation between languages by testing whether multiple languages are activated in neutral and biased sentence contexts over time (Experiments 5-7).

I outline the extent of top-down effects of context and motivation on multiple meaning access over time, both within and between languages. The results support a model of word recognition in which multiple meaning access occurs for both within-language and between-language competitors regardless of top-down context. Top-down semantic context modulates only the target language, both facilitating the appropriate meaning and inhibiting the inappropriate meaning. The implications of the results are discussed in context of the Reordered Access and Selective Access theories of lexical ambiguity resolution and BIA+ and BIMOLA models of bilingual word recognition.

The organization of this dissertation is as follows. In Chapter 2, background information for within-language lexical access and lexical ambiguity resolution, as well as for between-language lexical access is discussed. Chapter 3 describes the experiments testing frequency and context effects on homophone meaning resolution. Chapter 4 presents the experiments investigating motivational effects on lexical ambiguity

resolution. Chapter 5 describes the set of between-language experiments. A general discussion is provided in Chapter 6.

## CHAPTER 2

### BACKGROUND

#### 2.1 Spoken Word Recognition

In everyday conversations, people understand words rapidly and without much conscious effort. English speaking adults know tens of thousands of words. How do we use speech sounds and translate them into meaningful utterances so easily? Models of spoken word recognition attempt to explain the process of access of word meaning from a phonological input string.

Traditional models of spoken word recognition, such as Marslen-Wilson (1987), assume that there are three processes in spoken word recognition: access, selection and integration. Access is the mapping of speech sounds onto lexical representations in the mental lexicon, activating all possible candidates, at which time the lexical properties of the words become available. Selection is the reduction of the available candidates to the one that best matches the input. Integration is the process where the lexical representation's semantic and syntactic information is available to higher level sentence representations.

Spoken recognition models can be separated into two basic categories: autonomous and interactive. The stage at which context can affect lexical access differentiates models of spoken word recognition. Autonomous models (Forster, 1976, 1979; Norris, 1986; Seidenberg, 1985; Tanenhaus, Carlson, & Seidenberg, 1985;

Tanenhaus & Lucas, 1987) assume that lexical access and selection are completely driven by bottom-up sensory input and are thus autonomous from top-down, contextual influences.

Interactive models such as Morton's (1969, 1979) Logogen and TRACE (Elman & McClelland, 1984; McClelland & Elman, 1986) assume that sensory input and contextual influences are interactive. The earliest moments of lexical access and selection of lexical candidates can be affected by both bottom-up and top-down cues. In the Logogen model, context can affect activation levels of contextually-appropriate candidates even before acoustic information is available, and selection occurs once an activation threshold is reached. In connectionist models, words are activated by both lower and higher levels of representation (phoneme and sentence context) and inhibited within the word level. The most activated item in the end is selected.

Models that lie between autonomous and interactive models, such as Marslen-Wilson's original and revised Cohort models (Marslen-Wilson, 1980, 1984, 1987; Marslen-Wilson & Tyler, 1980; Marslen-Wilson & Welsh, 1978) assume that lexical access is sensory-driven and autonomous from top-down cues, but later stages, such as selection, can be influenced by context. An initial set of candidates that matches word-initial properties is accessed, and contextually-inappropriate items are either completely eliminated during the selection phase (Marslen-Wilson & Welsh, 1978), or their activation levels gradually decay (Marslen-Wilson, 1987), eventually leaving a single candidate for selection.

Using a cross-modal priming paradigm, Zwitserlood (1989) demonstrated that at early stages of word recognition, meanings for multiple members of a word-initial cohort

are temporarily activated, even in sentential context. Contextually-appropriate and inappropriate probes were equally activated at early probe positions, which is problematic for TRACE models (Elman & McClelland, 1984; McClelland & Elman, 1986), which claim that top-down context works at initial stages of processing to narrow the set of possible candidates. However, sentential context effects do emerge at the selection stage, which is inconsistent with purely autonomous models of word recognition that do not allow influence of top-down context to affect word recognition processes until after selection. Thus, a cohort model best describes Zwitserlood's results. Lexical access remains autonomous from top-down influences, but selection is influenced by context to narrow the set of candidates.

Much more recently, Allopenna, Magnuson, and Tanenhaus (1998) found evidence for activation of multiple word-initial cohort members in the visual world paradigm (see also Dahan, Magnuson, & Tanenhaus, 2001; Yee & Sedivy, 2006). However, they also provide evidence for activation of rhyme competitors that do not share word-initial phonemes, which is problematic for Cohort theories of word recognition. Cohort theories claim that only word-initial cohort members are activated during lexical access, eliminating all alternatives that do not match initial phonemes. Allopenna et al. favor a TRACE model interpretation of word recognition that allows for continuous bottom-up input to influence word recognition instead of a purely word-initial view (Elman & McClelland, 1984; McClelland & Elman, 1986).

Regardless of which model of word recognition is most appropriate, the aforementioned research on word recognition has demonstrated that multiple lexical candidates are activated during the word recognition process. This phenomenon is very

general in auditory word recognition, where most words are temporarily ambiguous. For example, incremental processing of the spoken word *captain* would temporarily activate words matching its initial phonemes /kæp/, such as *cap*, *caplet*, *capture*, *caption*, etc., which constitute the word-initial cohort.

Spoken lexical ambiguity resolution is a special case of cohort activation, in which the meaning is not resolved by bottom-up input. For example, *bat* temporarily activates word-initial cohorts *bad*, *bath*, *battery*, *balance*, etc., but also activates multiple meanings “winged animal” or “baseball equipment,” and which meaning was intended is unresolved without context. Homophones provide a particularly fruitful domain in which to investigate the role of context, as well as the inter-relationship between context and frequency. Although less common than the temporary ambiguities due to incremental word recognition, lexical ambiguities are prevalent within English and other human languages. Sections 2.2 and 2.3 focus on lexical ambiguity resolution as an extension of spoken word recognition research. As should become clear, research on the recognition of homophones will apply more broadly to spoken word recognition in general.

Speakers of more than one language may be required to resolve even more temporal ambiguities than monolinguals, because the cohort candidates activated during spoken word recognition are potentially multiplied by the number of languages the person speaks. The more similar the phonology between the languages, the greater potential for candidates from multiple languages to be part of the word-initial cohort. Depending on whether multiple languages are accessed at one time, a bilingual listener may need to eliminate words activated by the inappropriate language in addition to words

that do not match subsequent auditory signals. In Section 2.4, I focus on between-language activation in spoken language.

## 2.2 Lexical Ambiguity Resolution

Ambiguous words are prevalent within our language, yet we understand them relatively quickly and without much conscious effort. Consider the lexical ambiguity<sup>1</sup> in the following example: *Alice saw the flower/flour on the table*. In the auditory modality, the word *flower/flour* is lexically ambiguous, and the sentence is globally ambiguous in that the context does not distinguish whether the word refers to flower or flour. Depending on a listener's experience, she may choose a meaning quickly and effortlessly, with the intuition that she has retrieved only one meaning. Nonetheless, numerous studies have shown that multiple meanings of an ambiguous word are initially activated, even when the sentence is biased toward one of the meanings (e.g., Conrad, 1974; Swinney, 1979; Tanenhaus, Leiman, & Seidenberg, 1979). In contrast to non-homophonous words, where the phonological input disambiguates the meaning of the word prior to the end of the word, homophones are not inherently disambiguated by the spoken input. Consequently, homophones are a useful tool in elucidating meaning selection processes during spoken word recognition.

How one retrieves or chooses the appropriate meaning of an ambiguous word is a fundamental question in language comprehension. The two key variables are frequency and contextual support. Of these two, the role of frequency is most clear, especially for polarized ambiguous words, such that one meaning is much more frequent than the other.

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<sup>1</sup> In this paper, the term lexical ambiguity will refer to homophones, not polysemes. Homophones have more than one unrelated meaning, whereas polysemes have more than one meaning, each of which is related to the other meanings. Compare the homophone *flour/flower* to the polyseme *bed*, which has more than one related meaning: “a piece of furniture on which to sleep”, “a plot of ground prepared for plants”, etc.

When presented in a neutral linguistic context, the more frequent, dominant meaning of an ambiguous word is activated more quickly and persists longer than less frequent, subordinate meanings (e.g., Simpson & Burgess, 1985; Simpson & Krueger, 1991).

There is much more controversy surrounding the role of context<sup>2</sup> in lexical ambiguity resolution. While seminal research in the 1970's and 1980's made a strong case for multiple access in biasing sentential context (e.g., Seidenberg, Tanenhaus, Leiman, & Bienkowski, 1982; Swinney, 1979; Tanenhaus et al., 1979), later studies provided evidence that linguistic context can influence lexical access by increasing the availability of one of the meanings (Dopkins, Morris & Rayner, 1992; Tabossi, 1988) and that interactive processing of linguistic context occurs very early in word recognition (Sereno, Brewer & O'Donnell, 2003). Currently, most theories of lexical ambiguity resolution maintain that context influences lexical access to some degree, but the fate of the unsupported meaning—especially if it is the more frequent one—remains unresolved.

### *2.2.1 Theory of Reordered Access*

Most of the current debate in the domain of lexical ambiguity resolution rests on the fate of the dominant meaning when the context supports the subordinate meaning. *Reordered access* assumes that all meanings of homographs are made available, ordered by meaning frequency and contextual fit (Duffy, Morris, & Rayner, 1988; Duffy, Kambe, & Rayner, 2001). In contexts supporting subordinate meanings, reaction times to ambiguous words should be slow compared to unambiguous control words because both the dominant (boosted by frequency) and subordinate (boosted by context) meanings are strong competitors for selection. This is called the Subordinate Bias Effect (Binder, 2003;

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<sup>2</sup> In this paper, the term context will refer to sentence-level context, not intra-lexical context, in order to investigate top-down influences of higher sentence level context on lexical activation, rather than within-level lexical association.

Binder & Rayner, 1998; Kambe, Rayner & Duffy, 2001; Pacht & Rayner, 1993; Rayner, Cook, Juhasz, & Frazier, 2006; Rayner, Pacht & Duffy, 1994, Sereno, O'Donnell, & Rayner, 2006; Sereno, Pacht & Rayner, 1992).

The Subordinate Bias Effect is a well-established phenomenon under two conditions: (1) the homograph is strongly polarized, with subordinate meanings retrieved only about 10% of the time in word association tasks; (2) reading time for the homograph in subordinate context is compared to an unambiguous word matched to the homograph's form frequency—i.e., the sum of all meaning frequencies. When these conditions are *not* met, the results have been less consistent. For example, Wiley and Rayner (2000) did *not* find a Subordinate Bias Effect, using ambiguous words that were not strongly polarized and context passages that made use of titles for disambiguation. And Sereno et al. (2006, Experiments 2 and 3) actually found the *reverse* pattern when using a meaning-frequency control word: reading times were faster for highly polarized homographs in strong subordinate-biased contexts, compared to a control word that was matched in frequency with the subordinate meaning of the homograph. This finding seems to suggest that only the subordinate meaning of the homograph was accessed, but it is unclear why the homographs were faster than the control words—the authors themselves simply speculate and recommend further research. Sereno et al. (1992), who also failed to find the standard Subordinate Bias Effect, argued that a meaning-frequency control word is more appropriate than a form-matched control word, because the latter contrasts a high frequency (control) word with a low frequency word (the subordinate meaning of the homograph).

The issue of the appropriate control word is critical, although it is difficult to resolve because both word-form frequency and word-meaning frequency are likely to impact reading time. Furthermore, the fact that the Subordinate Bias Effect is so dependent on comparison against a high-frequency control word raises the concern that the Subordinate Bias Effect does not reflect competition between meanings after all, but rather the increased time it takes to access and integrate a lower-frequency word (as in Reichle, Pollatsek, & Rayner, 2006; Reichle, Rayner, & Pollatsek, 2003). Reichle et al. (2006) suggest that the Subordinate Bias Effect can be modeled in two ways. In their preferred account, slower reading times on the subordinate-biased homograph are due to competition from the dominant meaning. Because both meanings are activated and in competition, this is consistent with the Reordered Access model (Duffy et al., 1988, 2001). Reichle et al. (2006) also consider an account in which slower reading times for the subordinate-biased homograph are due to its low frequency, compared to the high-frequency control word. Such an account is consistent with selective activation of the subordinate meaning only, because it provides an explanation of the Subordinate Bias Effect without reference to activation of the dominant meaning.

### *2.2.2 Theory of Selective Access*

During the last 15 years, Kellas and colleagues have advocated for a Context-Sensitive or Selective Access account in which the dominant meaning is not activated if the context is sufficiently constraining toward a subordinate meaning. Evidence from lexical decision, naming and self-paced reading studies has demonstrated that in strongly-biasing contexts, reaction times to contextually-appropriate items are facilitated, but reaction times to contextually-inappropriate meanings are not (Kellas, Martin, Yehling,

Herman, & Vu, 1995; Kellas & Vu, 1999; Martin, Vu, Kellas, & Metcalf, 1999; Simpson, 1981; Vu & Kellas, 1999; Vu, Kellas, Metcalf, & Herman, 2000; Vu, Kellas, & Paul, 1998; Vu, Kellas, Petersen, & Metcalf, 2003).

In short, the fate of the dominant meaning in a strong subordinate context is a theoretically important question that differentiates two possible accounts of the Subordinate Bias Effect, and more generally, distinguishes between the Reordered Access and Selective Access accounts of lexical ambiguity resolution. The issue is whether top-down contextual cues can override the strong relationship between the word-form of an ambiguous word and its dominant meaning. This issue applies to both reading and listening paradigms. In fact, much of the ground-breaking research used spoken homophones in a cross-modal paradigm, leading to the conclusion that multiple meanings are accessed, even in biasing context (e.g., Onifer & Swinney, 1981; Swinney, 1979; Tabossi & Zardon, 1993; Tabossi, Colombo & Job, 1987; Tanenhaus et al., 1979). More recently, Huettig and Altmann (2007) found evidence that the dominant homophone meaning is activated in a subordinate-biased context, using a variant of the visual world paradigm introduced by Tanenhaus, Spivey-Knowlton, Eberhard, and Sedivy (1995).

### *2.2.3 Context Effects on Homophones in Eyetracking*

I take some time to review Huettig and Altmann's (2007) second experiment, both because of its similarity to the current set of studies and because it provides quite dramatic evidence of dominant meaning activation in subordinate context. Participants heard sentences containing polarized homophones, such as *pen*, while viewing an array of four line drawings. The drawings appeared one second before sentence onset in all conditions. In the neutral condition, the sentence contexts were neutral to the meaning of

the homophone, such as *The man got ready quickly, but then he checked the pen*. In the biased condition, the sentence contexts supported the subordinate meaning of the homophone, e.g., *The welder locked up carefully, but then he checked the pen*. In the neutral and biased conditions (25% of the trials), participants saw drawings depicting both meanings, along with two unrelated distracters. In the competitor condition, participants heard the subordinate-biased context sentence while a visual shape competitor (a sewing needle) replaced the dominant meaning (writing pen) (for evidence that looks to visual shape competitors track lexical access, see Dahan & Tanenhaus, 2005; Huettig, Gaskell, & Quinlan, 2004).

At homophone onset, before lexical access of the homophone had begun, Huettig and Altmann (2007) found no differences in looks to any objects in the neutral condition. However, in the biased and competitor conditions, the listeners were already fixating the pen-enclosure drawing 45% and 49% of the time, respectively, indicating that they had used the sentence context to fixate on sentence-relevant drawings.

At homophone offset, both dominant and subordinate referents were fixated more than fillers in both the neutral and the biasing conditions. In the neutral condition, presumably both meanings of the homophone were accessed due to support from two sources: the spoken word form and the images of two potential referents in the visual display. It is not possible to know for sure that meaning activation for the homophone was influenced by the visual display in this condition, but it seems likely, especially for the subordinate meaning. In the biased condition, the combination of sentence context and the visual display apparently activated the subordinate meaning prior to any phonological cues from the spoken homophone. Nonetheless, it is striking that the spoken

word-form of the homophone still prompted looks to the dominant, but contextually-inappropriate, referent. Even more striking is the fact that the pattern for the competitor condition was very similar to that in the biased condition, even though the dominant referent was replaced with a shape competitor. Looks to the shape competitor for the dominant meaning can be taken as evidence that the dominant meaning was activated, despite the subordinate context and the lack of an appropriate visual referent. Thus, this experiment provides very strong evidence for dominant meaning activation, even when a subordinate-biased context has successfully focused attention on the subordinate meaning.

The Huettig and Altmann (2007) findings provide compelling evidence that the word-form of a polarized homophone will *always* activate the dominant meaning, regardless of the linguistic and visual context. This begs the question: does the linguistic context have *any* effect on the activation of the dominant meaning? According to Reordered Access, a subordinate-biased context can boost activation of the subordinate meaning, thereby making the dominant meaning and subordinate meaning more competitive. But this does not entail delaying and/or limiting activation of the dominant meaning. The Reordered Access theory maintains that “prior disambiguating context does affect the access process by increasing the availability of the appropriate meaning without influencing the alternative meaning” (Duffy et al., 1988, p. 431). The same point has been made more recently: “The two meanings became activated independently. While context could speed activation of the intended meaning, it had no effect on the speed of activation of the unintended meaning” (Rayner, Binder, & Duffy, 1999, p. 847). Thus, in subordinate-biasing contexts, activation of the dominant meaning should be

unaffected, while the subordinate meaning should be activated earlier than usual. On the other hand, Selective Access assumes that the activation of the meanings of an ambiguous word depends on several constraints: frequency, type of context, and strength of context; the combined influence of these variables determines the meaning accessed (Martin et al., 1999). Thus, the subordinate-biasing context would serve to both boost activation of the subordinate meaning and limit activation of the dominant meaning.

#### *2.2.4 Homophone Frequency and Context Experiments*

In Experiment 1, I use a visual world paradigm similar to that of Huettig and Altmann (2007) to establish the extent of meaning activation for subordinate and dominant meanings of homophones in neutral context. In Experiment 2, I manipulate the linguistic context to determine how activations of both the subordinate and dominant meanings are affected.

#### 2.3 Motivational Effects on Lexical Ambiguity Resolution

As reviewed in Section 2.1, theories of spoken word recognition assume that lexical access is either autonomous from or interacts with top down influences (Forster, 1979; Elman & McClelland, 1984; Marslen-Wilson, 1987). Theories that assume that lexical access is autonomous do not allow top down influences like sentence context to influence the pattern of activation of lexical candidates. Theories that assume that lexical access is interactive with top-down influences do allow sentence context to influence the pattern of activation of lexical candidates. However, neither type of theory attempts to account for listener variables such as motivation. Regardless of whether motivation plays a direct role in lexical access, motivation may play an indirect role by affecting the ability of context to influence lexical access.

The logic of the conclusions from recent lexical ambiguity experiments relies on the assumption that participants attend to and comprehend the strongly subordinate-biasing contexts. For example, many eyetracking-during-reading studies have shown that a homophone's dominant meaning remains active during these subordinate biasing contexts (Binder, 2003; Binder & Rayner, 1998; Kambe et al., 2001; Pacht & Rayner, 1993; Rayner et al., 1994, 2006; Sereno et al., 1992, 2006), which is inconsistent with Selective Access (but see Kellas et al., 1995; Kellas & Vu, 1999; Martin et al., 1999; Simpson, 1981; Vu et al., 1998, 2000, 2003; Vu & Kellas, 1999, for evidence in support of Selective Access). However, to make the case that Reordered Access, rather than Selective Access, is supported, one relies on the assumption the subordinate-biased context was attended. Attention is necessary in order to process and maintain information during sentence comprehension (Baddeley & Hitch, 1974, 1994; Cowan, 2008). Even if the context itself is strongly biasing to the subordinate meaning, in order for the context to be effective, it is essential for the participants to attend to and understand the sentence. The assumption that participants fully comprehend the sentence contexts seems to be made implicitly in language experiments, but I argue that this implicit assumption may not be valid.

Participants may not fully comprehend the context for several reasons, one of which may be a lack of motivation to perform at their highest capacity. A common scenario for psychology experimenters is the use of participants who are unpaid and are required to participate in a minimum number of experimental hours for course credit. These participants, whose level of performance has no effect on their grade in the course, may not be motivated perform highly on the experimental task, and instead may be

motivated only to get the task done quickly. In this situation, the participant may be inclined to sacrifice performance for speed of finishing. This would result in poor performance on the experimental task, which in this case could include incomplete comprehension of the context sentence. Incomplete comprehension, in turn, may lead to dominant meaning activation during subordinate-biasing context, providing misleading support for Reordered Access.

### *2.3.1 Motivational Factors*

Economics experiments have often included factors like monetary incentive and feedback to improve participant motivation, which in turn is expected to reduce variability and produce more optimal performance from participants (Hertwig & Ortmann, 2001). Psychology research can be informed by these experiments to improve motivation and performance.

With respect to the current studies on lexical ambiguity resolution, changing environmental factors, such as monetary incentives, experimenter supervision, and feedback, may reduce the problem of inattention to the sentence contexts. The procedure of paying participants, either for a flat fee or a variable fee contingent on their performance, may alter the participants' motivation to complete the task properly, increasing their effort and performance. Experimental economics literature has shown that monetary incentives based on performance can increase speed and accuracy in decision making tasks (e.g., Hogarth, Gibbs, McKenzie, & Marquis, 1991; Jamal & Sunder, 1991; Wright & Aboul-Ezz, 1988). Bassi, Morton and Williams (2006) argue that payment can increase cognitive attention during experimental tasks to a level to that of people engaged in comparable tasks within a natural setting, increasing external

validation for the task. Monetary incentives have also influenced performance on low level tasks such as perception (Bahrick, Fitts & Rankin, 1952; Hayes & Keast, 2005), reaction time (Weinstein, 1981), and covert attention and activation of attention-related brain regions (Small et al., 2005)

The presence of an experimenter may also influence the motivation of the participant. In unsupervised situations, in which the participant completes the task alone without feedback, participants may be less willing to complete the task to their highest potential. In contrast, in situations in which the experimenter is in the same room and evaluating every response, participants may be more motivated to perform well, because they feel their performance is being evaluated. This situation can be likened to the Hawthorne effect, in which people are more productive when they know they are being studied (see Adair, 1984), and the audience effect: performance increases in the presence of an audience (see Zajonc, 1965). Experimental evidence of performance facilitation comes from experimental studies, where accuracy of visual detection increased when the participant was supervised, either directly in person or indirectly by video (Bergum & Lehr, 1963; Putz, 1975).

However, the mere presence of an experimenter may not be enough to motivate the participant, as shown by previous eyetracking during reading experiments. In a typical eyetracking experiment, an experimenter is necessarily involved with the participant because the experimenter must monitor the eyetracker to make sure the eye image and calibration are accurate throughout the experiment. Although the experimenter is present in this situation, a pattern of results supporting Reordered Access is often found (Binder, 2003; Binder & Rayner, 1998; Kambe et al., 2001; Pacht & Rayner, 1993;

Rayner et al., 1994, 2006; Sereno et al., 1992, 2006). Thus, motivational influences on performance may not rely on just one factor, such as experimenter presence, but a combination of motivational factors.

Decision making literature has shown that feedback can increase performance in experimental tasks (Briers, Chow, Hwang, & Lockett, 1999; Gupta & King, 1997). Studies have shown that sentence learning (Guthrie, 1971) and procedural learning (Naylor & Briggs, 1963) improved with the use of feedback.

These factors may motivate participants to improve their performance and may affect processing of the sentential context.

### *2.3.2 Naming Paradigm*

In order to explore the effects of motivation, we required a task in which monetary incentive, feedback and supervision could be manipulated. Visual world eyetracking tasks are not suitable for motivational manipulations because of several factors. First, the dependent variable is the fixation time on each of the pictured objects, which is taken to reflect processing of the spoken stimuli as it unfolds. Additions of monetary incentives and feedback may cause the eye fixations to become more strategic, and less automatic. For example, rewarding a participant to fixate only on the target object may induce the participant to strategically increase covert attention to peripheral objects, rather than allowing overt eye movements. This would affect the reliability of eye movements to reflect early lexical processing. Also, supervision cannot be manipulated because experimenters are inherently necessary in eyetracking tasks. Thus, I opted to use a reaction time paradigm adapted from previous lexical ambiguity experiments to evaluate motivational effects on context use.

The naming paradigm has been used to investigate context effects on lexical access (Duffy, Henderson & Morris, 1989; Simpson, Peterson, Casteel, & Burgess, 1989; Stanovich & West, 1979, 1981, 1983; West & Stanovich, 1982). In this paradigm, participants read a sentence and pronounced a target word that appeared in the sentence. Naming latencies for target words in sentence contexts that varied in predictability were recorded. Target words that were predictable by the sentence context were facilitated compared to the same words in neutral sentence contexts. Investigators have found that lexical processes are tapped in naming, as frequency affects naming latencies, and words are named faster than nonwords (Forster & Chambers, 1973). Naming latencies are also considered a fairly pure indication of lexical access because reading words aloud is highly practiced in adults (Forster, 1981). Although lexical decision has been shown to be more sensitive to semantic context effects than naming (Boland, 1997; Fischler & Bloom, 1979, 1980, 1985; Kleiman, 1980; Schwanenflugel & Shoben, 1985; Schwanenflugel, 1991; Stanovich & West, 1983), naming is nevertheless sensitive to context effects, as evidenced by semantic facilitation during naming (Duffy et al., 1989; Simpson et al. 1989) and facilitation of low-frequency and degraded words when they occurred in predictable sentence contexts (Stanovich & West, 1979, 1981, 1983; West & Stanovich, 1982). Although semantic context effects are usually larger in lexical decision than naming, naming is often preferred because of the possibility that lexical decision times reflect postlexical processes associated with the yes/no decision (Balota, 1990; Balota & Chumbley, 1984, 1985; Duscherer & Holender, 2005; Lorch, Balota, & Stamm, 1986; Neely, 1991; Neely & Keefe, 1989, Seidenberg et al., 1984; Stanovich & West, 1983; Theios & Muise, 1977; West & Stanovich 1982, but also see Allen, Smith, Lien, Grabbe,

& Murphy, 2005; Allen, Smith, Lien, Weber, & Madden, 1997). Another challenge for lexical decision is that their latencies are always slower than those in naming, supporting the claim that an additional post-lexical stage may be involved in the decision (West & Stanovich, 1982). In contrast, Duffy et al. (1989) claimed that naming does not reflect post-access integration difficulty because of a lack of inhibitory effects in naming when the target appeared in an incongruent sentence context.

The ability of the naming task to measure context effects on lexical processing makes it advantageous for the purpose of investigating lexical ambiguity resolution. Several studies of lexical ambiguity resolution have utilized the naming paradigm (Martin et al., 1999; Simpson & Krueger, 1991; Tanenhaus et al., 1979, Vu et al., 1998, 2000, 2003). In these studies, contexts biasing either the subordinate or dominant meaning of a homophone are read prior to the naming of a probe word that is related to either the subordinate or dominant meaning. Associates of the dominant meaning are not named any faster than unrelated control words after a subordinate context, indicating that participants, unlike in eyetracking studies, successfully used the sentence contexts to activate only the appropriate meaning of the homophone.

### *2.3.3 Motivation Experiments*

Experiments 3 and 4 manipulate task and environmental variables to determine whether increased participant motivation limited access to contextually irrelevant meanings by increasing effort and performance and affecting comprehension of the sentence contexts.

## 2.4 Bilingual Lexical Activation

There are over 6,000 languages spoken in the world, and over half of the world's population is multilingual, using more than one language (Grosjean, 1982). Multilinguals use different languages depending on factors such as the particular situation, particular interlocutor, and purpose of communication (Fabbro, 1999).

Intuitively, bilinguals may have the perception that when they are speaking in one language, they only access words in one language. For example, a Spanish-English bilingual reading a manuscript in Spanish may only be aware of Spanish words and meanings. Although a bilingual may be conscious of only one language entering his or her mind, recent studies in bilingual word recognition have shown that access to words is not selective to one relevant language (De Groot, Delmaar, & Lupker, 2000; Dijkstra, 2005; Dijkstra, Grainger, & Van Heuven, 1999; Dijkstra, Timmermans, & Schriefers, 2000; Grainger & Dijkstra, 1992; Van Heuven, Dijkstra, & Grainger, 1998).

A large number of studies of visual word recognition investigated how the bilingual mental lexicon is organized. Two theories of bilingual lexical access explain how more than one language is organized and accessed in the mind of a bilingual. The theory of *language-selective access* holds that processing in one language does not activate another language, and only words in the target language are ever activated. The theory of *language-nonsselective access* holds that processing in one language activates another language, so that meanings of a word from both target and nontarget languages are activated (Dijkstra, 2005). Researchers have provided evidence for both theories; however, the current literature assumes language-nonsselective access. Although

language-nonspecific access is commonly accepted, it is important to outline both views of language access.

#### 2.4.1 Language-Selective Access

Early evidence supporting language-selective access comes from studies using lexical decision experiments (Gerard & Scarborough, 1989; Scarborough, Gerard, & Cortese, 1984). Gerard and Scarborough (1989) recruited Spanish/English bilinguals to perform lexical decision tasks in Spanish and English. Lexical decision is quite sensitive to word frequency, with more frequent words leading to faster “yes” responses (Rubenstein, Garfield & Millikan, 1970; Scarborough, Cortese, & Scarborough, 1977). In order to test whether language-selective or language-nonspecific access governed word recognition, the experimenters manipulated the language in which Spanish/English interlingual homographs with different frequencies were tested<sup>3</sup>. Homographs had high frequency of occurrence in one language, and their meaning in the other language had low frequency. For example, *fin* (means “end” in Spanish) is high frequency in Spanish but low frequency in English, and *red* (means “net” in Spanish) is high frequency in English but low frequency in Spanish.

A language-selective access account would predict that lexical decision times should be governed by the frequency of the word in the specific language. In the English lexical decision, a homograph with high frequency in English (*red*) should be no different than a high-frequency control word in English, and both should be faster than a homograph with low frequency in English (*fin*), and low-frequency controls. The same homographs should show the opposite pattern of frequency effects in Spanish. In

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<sup>3</sup> An *interlingual homograph* is a word that has identical spelling across two or more languages, but differs in pronunciation or meaning across languages. Compare interlingual homographs to *cognates*, which are words that share both spelling and meaning across languages.

contrast, a language-nonspecific access account would predict that lexical decisions times should be governed by the overall frequency of the word across both languages. Thus, a lexical decision to *red* or *fin* in either target language should be just as fast as a lexical decision to a high frequency control word in the target language.

The results of the experiment supported the language-selective access hypothesis. Bilinguals produced the same pattern of results as English monolinguals in the English lexical decision task, such that homographs with high frequency in English, but low frequency in Spanish, looked like high frequency controls, and homographs with low frequency in English, but high frequency in Spanish, looked like low frequency controls. The same homographs, when tested in Spanish, varied only with Spanish word frequency. Gerard and Scarborough concluded that word recognition depends on language-specific processing, and the lexicons of multiple languages are separate.

Although the evidence from Gerard and Scarborough (1989) supported selective access, additional studies showed that the absence of nontarget language effects could have been due to combined inhibitory and facilitative effects. Dijkstra et al. (1999) demonstrated that interlingual homographs that overlap in orthography facilitate lexical decisions compared to controls, but when they also overlap in phonology, they produce inhibitory effects. The combination of orthographic and phonological overlap of homographs in the materials of previous experiments could suppress differences between homographs and their control words, creating a misleading language-selective access outcome.

#### 2.4.2 Language-Nonselective Access

Evidence for language-nonselective access came from several word recognition studies (De Groot et al., 2000; De Moor, 1998; Dijkstra et al., 1999, 2000; Grainger & Dijkstra, 1992; Van Heuven et al., 1998). De Moor (1998, as cited in Dijkstra, 2005) examined Dutch/English bilinguals in an English lexical decision task, but looked at the amount of priming from one trial to the next as the critical dependent variable. Participants were asked to perform an English lexical decision to an interlingual homograph, such as *brand*, which has meanings both in Dutch and English (in Dutch, *brand* means “fire”). The critical trial was the second trial, in which the participant performed an English lexical decision to the English translation of the Dutch meaning of the previous homograph. In this example, the critical second trial was a lexical decision on *fire*.

A language-nonselective access account would predict that the second lexical decision should be affected by the first trial, because the first trial activated the nontarget language meaning of the homograph, which would prime the lexical decision of the English translation of the nontarget meaning. In contrast, a language-selective access account would predict that the second lexical decision should not differ from any control trial because the nontarget Dutch meaning of the homograph was never activated. The results demonstrated that the critical second lexical decision reaction time was faster when preceded by a homograph translation than when preceded by a control word. It appeared that the nontarget language meaning of the homograph primed the lexical decision of its translation. The priming from one trial to the next suggested that bilingual lexical access is nonselective (De Moor, 1998).

The nonselective nature of bilingual lexical access can also be shown with neighborhood effects. Orthographic neighbors were used to examine the relative influence of nontarget language words on target language word recognition in Grainger and Dijkstra (1992). Dutch/English bilinguals participated in an English lexical decision task. The experimenters varied the number of Dutch neighbors of an English word in an English lexical decision task. A language-selective access account would predict that increasing the number of Dutch orthographic neighbors should not affect processing during the English lexical decision because only English words should be active. The results, however, showed that increasing the number of Dutch neighbors slowed the English lexical decision time, supporting language-nonselective access, and demonstrated that the bilingual lexicon is integrated in respect to orthographic codes. The majority of the literature on bilingual word recognition has supported nonselective language access. This nonselective nature of bilingual lexical access is captured in current models of bilingual word recognition. Two current models of bilingual lexical activation, the Bilingual Interactive Activation + Model (BIA+) and the Bilingual Model of Lexical Access (BIMOLA). Both models are interactive in nature, but have fundamental differences in how language-nonselective access is achieved.

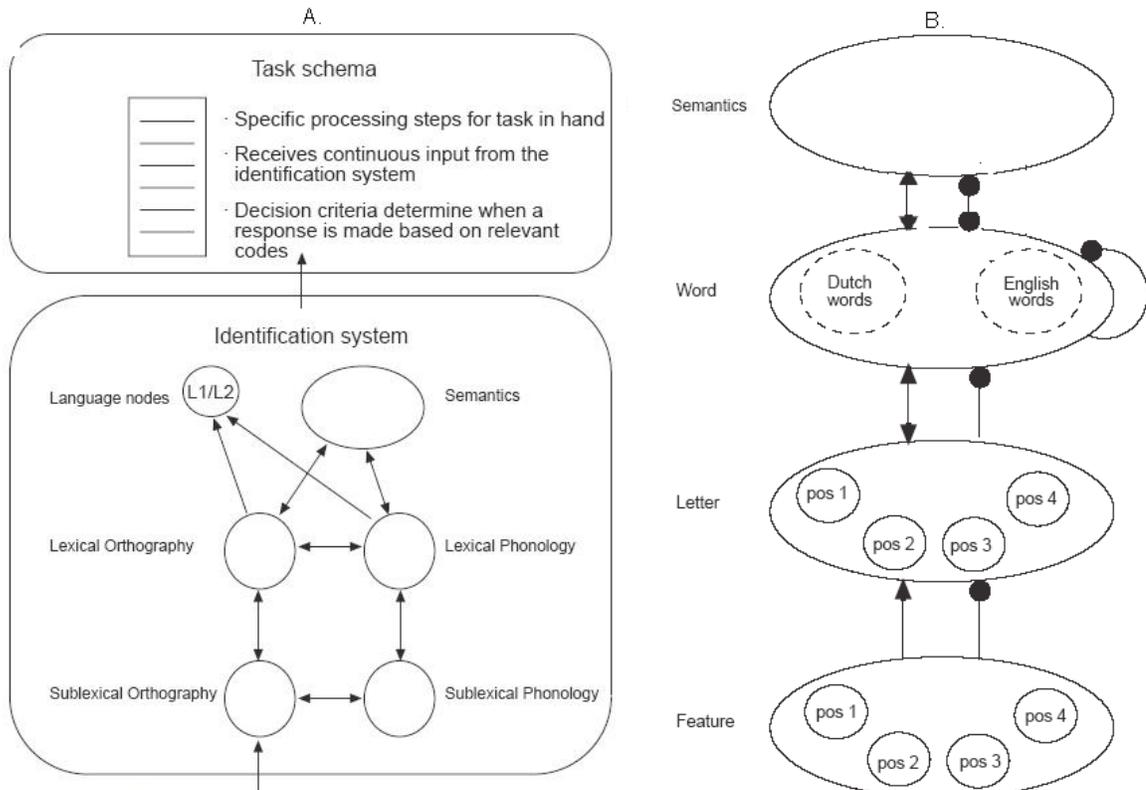
#### *2.4.3 Bilingual Interactive Activation + Model (BIA+)*

The Bilingual Interactive Activation + (BIA+) (Dijkstra & Van Heuven, 2002) (see Figure 1) is a model of bilingual word recognition that assumes that lexical access is nonselective in nature. The architecture is similar to McClelland and Rumelhart's (1981) Interactive Activation Model, which has orthographic feature, letter, and word levels. BIA+ modifies the Interactive Activation Model to incorporate orthographic,

phonological, semantic, and language node representations in the word identification system. Word identification gets input from not only phonology and orthography from multiple languages, but also from semantics and syntax from different languages. The key difference between this model and the BIMOLA is that in the BIA+, multiple lexicons are stored at the word level, forming an integrated lexicon. All nodes regardless of the language in the word level are interconnected, and they mutually inhibit each other. In addition, this model is different from most models of word recognition because it incorporates a layer of semantic nodes, which interact directly with word identification. The BIA+ additionally assumes that context effects are nonselective, such that context effects do not only influence one, but multiple languages. Thus, the model is not only language-nonselective with respect to bottom-up lexical access, but also language-nonselective with respect to top-down linguistic context. In order to have the ability to discern to which language a word belongs, language nodes represent language membership in the word identification system. These language nodes do not filter one language from another, and its effects on word recognition are small.

In sum, this model of bilingual lexical activation is interactive and consists of an integrated lexicon that activated languages nonselectively. It is the only model of bilingual language activation that explicitly describes how semantic information is processed with respect to word-level interactions. It assumes that semantic-level influences are language-nonselective.

Figure 1. The BIA+ model for bilingual word recognition (Dijkstra & Van Heuven, 2002, p. 182). Part A shows the entire BIA+, with division of task schema (nonlinguistic information) and word identification system, which incorporates linguistic information. Part B shows a subset of the word identification system, showing the information flow from orthographic features to letters, words, and the interaction with semantics on the word level. Note that the word level integrates words from both languages, and all words in this level inhibit one another. Semantic effects are language-nonspecific.

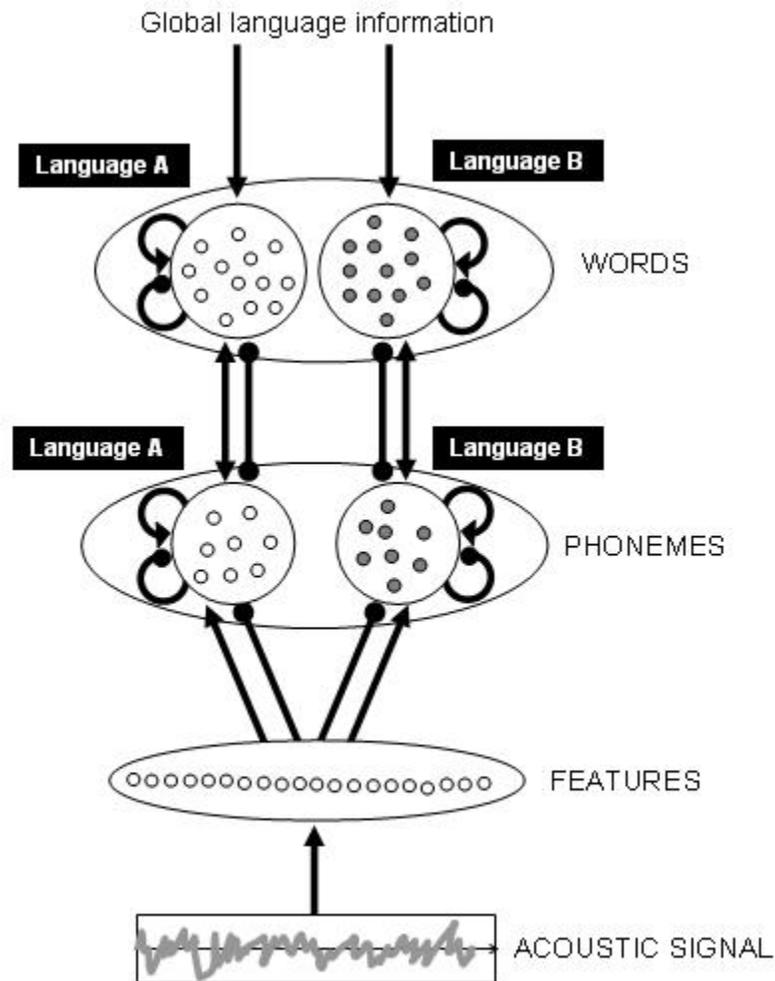


#### 2.4.4 Bilingual Model of Lexical Access (BIMOLA)

The Bilingual Model of Lexical Access (BIMOLA) (Grosjean, 1988, 1997; Lewy & Grosjean, in preparation) captures language-nonspecific processing using interactive networks based on the TRACE model of spoken word recognition (Elman & McClelland, 1986) (see Figure 2). The main difference between this model and the BIA+ is the independence of the two language networks in the BIMOLA. Although both models are language-nonspecific with respect to processing of bottom-up input, differences emerge in the way the two languages are represented. In the BIA+, both languages' lexicons are

integrated at the word level, and in the BIMOLA, the languages are stored in separate networks starting at the phoneme through the word level.

*Figure 2.* The Bilingual Model of Lexical Access (BIMOLA) (Lévy & Grosjean, in prep, as depicted in Thomas & Van Heuven, 2005, p. 211). A model of bilingual speech perception.



In the BIMOLA, the lowest feature level is common to both languages. The networks for each language are separated starting at the phoneme and word levels, such that each language is a separate subset of the phoneme or word level. Thus, languages are organized independently within the phoneme and word levels, and can excite or inhibit between levels only within a language. Each language does not directly interact with the

other. Features excite and inhibit phonemes in both languages in parallel, but the phonemes interact with the word level only within the respective language. Global language information, such as language mode, the bilingual's base language, and higher linguistic information (syntax, semantics) affects each language network separately. Language activation occurs both from the top-down language information and from within-language connections at the phoneme and word levels. In contrast, with the BIA+, which specifies that semantic context affects word activation in a language-nonspecific manner, the BIMOLA maintains that influence of semantic context is language-specific.

The BIMOLA predicts that words and consonant clusters that are specific to one language only will increase the overall activation of its language network and speed the recognition of words in that language. Phonemes that are similar across languages will be activated to a similar degree, but phonemes that are quite different between languages will not be activated to the same degree. When in a bilingual language mode, both language networks will be activated, but the carrier language network will be the most activated. The level of activation of the second language network is determined by the amount of mixed-language interaction (bottom-up) or changes in global language information (top-down). When in a monolingual mode, the target language network is strongly activated, and the nontarget language network is very weakly activated, with a low resting activation level.

In sum, both the BIA+ and the BIMOLA capture language-nonspecific activation; however they do this in different ways. BIA+ captures language-nonspecific activation by integrating multiple lexicons at the word level, such that the words compete against one another, regardless of the language. BIMOLA captures language-nonspecific

activation by allowing parallel activation of multiple non-overlapping language networks, such that if the features match phonemes from multiple languages, each network will be activated in parallel.

#### 2.4.5 Context Effects and Bilingual Lexical Activation

Although lexical activation is found to be language-nonspecific, it is possible that higher level linguistic information could affect lexical processing. For example, a salient linguistic context in the target language may be able to modulate nonspecific language activation. However, the majority of the literature on bilingual lexical activation has used single word recognition tasks. Few studies have dealt with bilingual lexical access in more natural sentence-level contexts, and even fewer in spoken language domains. This is surprising, given the extensive literature on context effects in monolingual lexical access. Of the few studies that have investigated context effects in bilingual lexical activation, each has important contributions to bilingual literature, but has methodological problems that make the interpretation of their results difficult.

The first study to examine context effects on lexical processing in bilinguals was Altarriba, Kroll, Sholl, and Rayner (1996). They examined eye movements while participants read sentences on a computer screen. The sentences were read in English, and had either a high-constraint or low-constraint context on the critical word, which was either in Spanish or English. For example, a high-constraint context was “He wanted to deposit all of his *money/dinero* at the credit union,” where only a few restricted words (money, cash, checks) could be inserted at the target position. A low-constraint context was “He always placed all of his *money/dinero* on a silver dish in his dresser,” where fewer restrictions are placed at the target position. A difference in reading times in low

and high-constraint contexts, regardless of language, would indicate modulation by semantic context.

The experimenters also varied the frequency of words in the target position. If frequency effects varied with sentence context, it would be evidence that sentence context can influence lexical processing, because frequency effects are attributed to lexical processing, rather than conceptual processing. The results showed that frequency and type of constraining context interacted with Spanish targets. When the English context was highly constraining and the Spanish word had high frequency of occurrence, the participant spent more time reading the word than in any other condition. The experimenters attribute this to the fact that in high-constraint contexts, the semantic features of the target are highly activated, and because the highly frequent Spanish word mismatched with the expected lexical properties, interference occurred.

These results provided evidence that sentence context interacts with bilingual lexical processing, such that lexical properties of the nontarget language word interfered the most in semantically constraining contexts. This contribution is important because it demonstrates interactions between semantic and lexical level processing, instead of independent processes. However, Altarriba et al. (1996) cannot answer the question of whether sentence level context can influence language-nonspecific activation. Because the stimuli in Altarriba et al. (1996) involved code-switching (two languages mixed), both languages were activated from bottom-up sources, the data does not inform us about the activation of second languages when only one language is presented.

Duyck, Van Assche, Drieghe, and Hartsuiker (2007) explored sentence context effects on language activation using monolingual English sentences for Dutch/English

bilinguals. Using both a lexical decision task and eyetracking during reading, Duyck et al. presented low-constraining sentence contexts ending in cognates, for example, *Lucia went to the market and returned with a beautiful cat [cognate]*. If the monolingual sentence context is able to modulate nonselective language access, then lexical decision times to the cognates should look similar to frequency-matched controls. If the sentence context is unable to modulate nonselective language access, then cognates should be facilitated compared to controls, as found in previous single-word recognition experiments (Caramazza & Brones, 1979; Dijkstra et al., 1999; Van Hell & Dijkstra, 2002). In fact, the lexical decision time results showed that both identical and nonidentical<sup>4</sup> cognates were recognized faster than their controls, and identical cognates were recognized faster than the nonidentical cognates. The eyetracking results showed that for identical cognates, three measures of eye fixations, first fixation duration, gaze duration, and cumulative region reading time, indicated facilitation for cognates compared to controls. However, nonidentical cognates did not generate any facilitation. Duyck et al. concluded that even in sentence contexts, language activation remains nonselective; however, the effects of sentence context increase when cognates are nonidentical. Nonidentical cognates, which do not overlap entirely in orthography, may be more sensitive to context effects because of their weaker activation compared to cognates.

Duyck et al. (2007) showed that in low-constraint monolingual sentence contexts, sentence context does not affect language-nonselective activation. Nonselective language activation was measured by the facilitation of cognates, which could only be facilitated

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<sup>4</sup> Identical cognates shared identical spelling between languages. Nonidentical cognates shared similar but not identical spelling, e.g., *schip* (Dutch)– *ship* (English).

compared to controls if activation in the second language aided lexical access. However, low constraint monolingual contexts may not be salient enough to modulate language-nonspecific activation. Instead, stronger linguistic contexts should be tested to investigate contextual influences on bilingual lexical activation.

In order to investigate whether semantically constraining sentence contexts affect nontarget language activation, Schwartz and Kroll (2006) used a rapid serial visual presentation method (RSVP). In this method, words were presented one at a time on a computer screen, such that sequential words replaced previous ones, and the participant was required to pronounce one of the words, indicated by a differing color. The target word in the following examples was the cognate. They presented either high-constraint sentences, e.g., “Before playing, the composer first wiped the keys of the *piano* at the beginning of the concert”, or low-constraint sentences, “When we entered the dining hall we saw the *piano* in the corner of the room.”

Schwartz and Kroll (2006) found similar results as Duyck et al. (2007), that cognates are facilitated when embedded in low-constraint sentence contexts. Conversely, they found that that cognate facilitation disappears when cognates are embedded in high-constraint sentence contexts. This result is consistent with the BIA+, in that semantic context can affect word identification. The authors concluded that sentence context can modulate language-nonspecific access with sufficient linguistic information, such as in high-constraint sentence contexts. However, this finding is complicated by the fact that the high-constraint context did not control for intralexical priming (Forster, 1979). What Schwartz and Kroll considered to be top-down semantic context may be in fact a lexical-level effect of priming (Seidenberg et al., 1982). Their cloze norming values for the high-

constraint and low-constraint sentences (0.67, and .05, respectively) indicate that lexical priming may have allowed the high-constraint sentences to selectively activate the target language. Therefore, Schwartz and Kroll confirm Duyck et al.'s finding that nonselective access is found in low-constraint sentence contexts, but because their high-constraint contexts may have been confounded with intralexical priming effects, their results may not inform the literature about sentence level effects.

More recently, Van Hell and De Groot (in press) used a version of the lexical decision paradigm to test strength of sentence constraint on nontarget language activation. Participants were visually presented with an entire sentence context for 10 seconds, with the target word replaced by dashes. The target word was located in the last position of the sentence in half of the trials and in the middle of the sentence for the other half. The sentence disappeared simultaneously with the appearance of the target word, and the participants were required to make a lexical decision to the target. The sentences were either high-constraint context sentences, e.g., *The best cabin on the ship belongs to the captain*, or low-constraint context sentences, e.g., *The handsome man in the white suit is the captain*.

Like Schwartz and Kroll (2006), Van Hell and De Groot (in press) found cognate facilitation for the low-constraint sentence contexts, but no facilitation during high-constraint sentences. The authors concluded that sentence context can modulate language-nonselective access with sufficient contextual information. Their findings, however, are complicated by the fact that they did not use an on-line method of sentence presentation, instead requiring lexical decision of the target word after comprehension of the sentence context. This version of the lexical decision task is also complicated by

weaknesses of previous lexical decision tasks, in that the task may not measure initial lexical activation processes, but post-lexical decision processes (Balota, 1990; Balota & Chumbley, 1984, 1985; Duscherer & Holender, 2005; Lorch et al., 1986; Neely, 1991; Neely & Keefe, 1989, Seidenberg et al., 1984; Stanovich & West, 1983; Theios & Muise, 1977; West & Stanovich 1982). Without the ability to reveal early lexical processes, one cannot evaluate whether the nontarget language was active during initial lexical access.

Thus, methodological concerns in Schwartz and Kroll (2006) and Van Hell and De Groot (in press) due to intralexical priming and off-line judgments render the conclusions about high-constraint context effects on nontarget language activation unreliable. However, data from these three reading studies do converge to show nontarget language activation during low-constraint sentence contexts (Duyck et al., 2007; Schwartz & Kroll, 2006; Van Hell & De Groot, in press).

In sum, Duyck et al. (2007) found nonselective access using a low constraint sentence context, but it is possible that a more highly constraining sentence context may limit activation of the nontarget language. However unlike Schwartz and Kroll (2006), the high-constraint sentence contexts must not contain lexical associates, in order to investigate top-down effects of context on lexical activation. Altarriba et al (1996) showed that sentence context does interact with lexical processes in bilingual sentence processing.

Although both the BIMOLA and the BIA+ allow for interaction between sentence level and word level processing (Altarriba et al., 1996), the two models diverge in whether the influence of semantic context is language-nonselective or language-selective. The BIA+ assumes that influence of semantic context is language-nonselective. Because

the lexicons of multiple languages are integrated, semantic influences on the word level could not affect each language separately. In contrast, the BIMOLA describes the effects of global language information on word level processing as specific to a language network. Thus, semantic influences are language-selective in the BIMOLA.

#### *2.4.6 Eyetracking and Bilingual Lexical Activation*

In order to test the effects of sentence context on language-nonselective activation, it was necessary to use a method that allowed the manipulation of sentence contexts and the measurement of meaning activation for words from multiple languages. Eyetracking in the visual world was chosen because it allowed for multiple meanings to be tested during spoken sentence contexts and was able to provide detailed time course information about meaning activation, which is important for measuring lexical processes. In addition, the paradigm had been successfully used in bilingual word recognition studies (Marian & Spivey, 2003; Marian, Spivey, & Hirsch, 2003; Spivey & Marian, 1999). In their series of studies, Spivey and Marian (1999) developed a method utilizing the visual world paradigm to investigate whether a nontarget language would be activated when the language environment was only in the target language in a spoken word recognition task. Russian/English bilinguals heard Russian instructions like *Poloji marku nije krestika* (“Put the stamp below the cross”) simultaneously with the presentation of four objects: 1) the Russian target picture: *marku* (“stamp”), 2) an English phonological competitor marker, and two unrelated filler objects. The English phonological competitor shared the same initial phonemes as the Russian target.

The critical analysis in this experiment was the comparison of average proportion of looks between the English phonological competitor and the filler objects for each trial.

The Language Mode Framework would predict that because the spoken language is Russian, the participants would be in a Russian language mode and thus, access words only in the Russian lexicon. The English phonological competitor would not be activated. However, the results indicated that even though the spoken input was in Russian, there were still more looks to the English competitor (32%) than to the filler objects (7%). Thus, the phonological input activated both lexicons as the word unfolded over time, even when the language environment was purely monolingual. This evidence, confirmed in Marian and Spivey (2003) and Marian et al. (2003), suggested that language-nonspecific access not only governs visual word recognition, but also in the spoken language domain, even at the sub-lexical level. Nonspecific language access was found, even when the monolingual mode was strictly controlled by using monolingual Russian speakers for stimuli construction, having participants interact with monolingual Russian experimenters, not emphasizing language as the topic of study, and not referring to the participant as a bilingual (Marian & Spivey, 2003).

However, concerns about the methods of these studies limit their interpretation (Marian et al., 2003, Marian & Spivey, 2003; Spivey & Marian, 1999). Although they report a pattern of nonspecific access during monolingual language contexts, there was no indication of how soon these effects appeared. No real-time data were reported, as data were summed over entire trials. A trial often last several seconds, which is a longer time interval than normally recorded for lexical processing. In addition, in Marian and Spivey, each target object was actively named before being repeated three more times in separate trials during the experiment. This repetition and knowledge of the materials may have induced strategic looking patterns.

Although this series of studies have found that nonselective language activation occurs during monolingual sentence contexts, it remains unknown whether higher linguistic context effects, such as semantic context may play a role in language-nonselective lexical activation. The monolingual context sentences of Spivey and Marian (1999), such as “Put the stamp below the cross” are sentence contexts with very little meaning attached to them, since every trial in the experiment used the same canned instruction. These instructions may not have provided enough linguistic material for the monolingual language mode to be dominant. However, if the sentence context is made more salient to bias only the meaning of a word in the target language, it may be able to suppress lexical activation in the nontarget language.

#### *2.4.7 Bilingual Experiments*

Experiments 5-7 investigated top-down influences on multiple language activation over time by using sentence contexts that conceptually-biased the meaning of a word in the target language, in an eyetracking during listening paradigm. These experiments were an improvement from previous studies on context effects in bilingual lexical activation because they provided online measures of meaning activation. In addition, the sentence contexts used in the present experiments used conceptually biasing contexts that did not include lexical associates, in order to rule out intralexical priming as a factor in modulating language-nonselective activation. By utilizing the eyetracking during listening paradigm, detailed information about the time course of meaning activation could be measured.

Experiment 5 provided a baseline level of language activation for Spanish-English bilinguals during neutral context. Experiments 6 and 7 investigated effects of neutral and

biasing contexts on multiple language activation in English and Spanish to determine whether semantic context can modulate nonselective language activation, and also to determine whether semantic context effects are language-selective or nonselective.

## CHAPTER 3

### FREQUENCY AND CONTEXT EFFECTS ON HOMOPHONES

The heart of the conflict between the two major theories of lexical ambiguity resolution rests on the fate of the dominant meaning when presented in a subordinate-biased sentence context. *Reordered Access* maintains that all meanings of homophones are made available, ordered by meaning frequency and contextual fit (Duffy et al., 1988, 2001). In a strong subordinate context, the subordinate meaning receives a boost of activation due to the sentence context, but the dominant meaning remains active because of its inherent frequency. In contrast, *Selective Access* maintains that the resolution of meaning of an ambiguous word depends on several constraints: frequency, type of context, and strength of context, and the combined influence of these variables determines the meaning accessed (Martin et al., 1999). The factor of contextual strength has the opportunity to dominate the processing of the ambiguous word, so in a case that the subordinate context is sufficiently strong, frequency does not play a large role in meaning activation, leading to suppression of the dominant meaning.

To investigate the role of frequency and context on homophone meaning activation, I employ a visual world paradigm similar to Huettig and Altmann (2007). In order to display targets representing both homophone meanings together, one meaning was depicted using an actual referent picture and the other meaning was depicted by a visual shape competitor (Dahan & Tanenhaus, 2005, Huettig et al., 2004).

The following questions are addressed in Experiments 1 and 2:

- Is a shape competitor a suitable alternative to an actual homophone target to measure homophone meaning activation in the visual world paradigm? (Experiment 1)
- What is the extent of meaning activation for subordinate and dominant meanings of homophones in neutral context in the visual world paradigm? (Experiment 1)
- How does top-down sentential context affect the activation of each of the subordinate and dominant homophone meanings, in the absence of visual preview? (Experiment 2)

### 3.1 Experiment 1: Frequency Effects on Homophones

Experiment 1 explored dominance effects on the activation of multiple meanings of ambiguous words in an instructional eye-tracking during listening task. This is somewhat analogous to the neutral condition of Huettig and Altmann (2007), described in Chapter 2, but there are three important differences. First, instead of using a declarative sentence, I used imperatives that directly engaged the listener (“Look at the flower/flour”), in the tradition of Dahan et al. (2001). The use of imperatives may increase the number of looks to the critical objects, thus allowing for more data points for comparison during analysis.

Second, I presented the visual stimuli coincidentally with the onset of the target word (a homophone in the current experiments), rather than at trial onset, in order to limit the degree to which the visual context constrains lexical activation. Without a preview of the visual items, it is less likely that the participants engage in strategic processing of the visual objects prior to lexical access. These changes were intended to get a clearer picture

of the time-course and extent of activation for the dominant and subordinate meanings, as reflected by fixation patterns in this paradigm, when meaning frequency is the only relevant factor.

Third, rather than presenting two meanings of the polarized homophones directly, one meaning was depicted using an actual referent picture, and the other meaning was depicted by a visual shape competitor (Dahan & Tanenhaus, 2005, Huettig et al., 2004). For example, the dominant meaning of the homophone *flower/flour* was directly depicted using a picture of a *flower*, and the subordinate meaning was indirectly depicted using a pillow as a visual shape competitor for *flour*. On another trial, the subordinate meaning of *flower/flour* was depicted using a picture of *flour*, and a lollipop was used as a shape competitor for the dominant meaning *flower*. Although an actual referent for the homophone was always in the visual display, residual activation of the alternative meaning of the homophone could be assessed by analyzing the looks received by the shape competitor. As in Dahan and Tanenhaus (2005), none of the shape competitors overlapped in phonology with the spoken referent names, so any activation of the shape competitor from the spoken input indicated activation of its homophone referent. The activation of multiple meanings of the ambiguous word was measured by comparing looks to the shape competitor picture on trials where the dominant or the subordinate actual item was pictured. A relative dominance effect would be found if pictures of dominant meanings of a homophone attracted more looks than pictures of subordinate meanings. Because I needed to compare the probability of looking at two different pictures, it was crucial to match the pictures on various dimensions, as described in the normative measures below.

### 3.1.1 Methods

#### *Participants*

Thirty undergraduates at the University of Michigan participated in this experiment for partial course credit in an Introductory Psychology class. All participants in this and the following experiments were native speakers of English and had normal or corrected vision.

#### *Materials*

I collected word association norms for a set of heterographic and homographic homophones (details below) and chose the 14 homophones for which meaning dominance was most polarized. Each homophone had two distinct, imageable meanings (see Appendix A).

The auditory stimuli were recorded by a female speaker: *Look at the cross. Now look at the (homophone)*. For each digital speech file, silence was added before the onset of the spoken instructions as needed (i.e., before *Look at...*), so that the onset of each critical homophone was 3000 ms from the beginning of the auditory stimulus.

For each meaning of each homophone, two critical pictures were selected. One depicted the referent of the homophone (Actual Referent), and one depicted an object that was similar in shape to the homophone referent (Shape Competitor). The norms used to assess shape similarity are described below.

Visual stimuli consisted of four pictures arranged on a white background with a fixation cross in the center for each critical trial. The critical pictures were all full-color realistic images selected from an online searchable database of images (Google, 2004). Actual Referent images were chosen so that the picture represented a typical instance or

instances of the object, and such that the picture would not be identified with other possible labels. For example, a *stamp* with an unknown design was chosen so that the participants would not identify the stamp with its design, such as an “American flag”. In the case of *letter*, the Actual Referent included multiple letters in order to prevent the picture to be labeled as the letter itself, such as “B”. Shape Competitor images were selected so that the picture was as identifiable as the Actual Referent and would not be assigned a label that overlapped in phonology or semantics.

The pictures appeared in the upper-left, upper-right, lower-left, or lower-right quadrant, arranged so that the Actual Referent appeared in each quadrant an equal number of times for every participant (see Figure 3). The Shape Competitor also appeared in each quadrant an equal number of times for every participant. The two remaining quadrants contained filler pictures of objects with unambiguous names that did not begin with the same phonemes as the critical homophone and were not similar in shape to the critical pictures.

Figure 3. Experiment 1 example visual stimuli. Actual Referent *flour* is displayed with Shape Competitor *lollipop*, which resembles a flower, and two unrelated filler objects.



Each homophone was tested only once, with each auditory stimulus occurring with one of two visual display types: Dominant-Actual or Subordinate-Actual. In the Dominant-Actual display, participants viewed the Actual Referents of the dominant meaning of the homophones, together with the Shape Competitors of the subordinate meaning of the homophones. In the Subordinate-Actual display, participants viewed the Actual Referents of the subordinate meaning of the homophones, together with the Shape Competitors of the dominant meaning of the homophones. Display type was varied between participants because I was concerned that the Shape Competitors would get relatively few looks, and I wanted to maximize statistical power for comparisons evaluating the hypothesis that Shape Competitors received more looks than would be

expected by chance. Each participant was randomly assigned to one of the two display types.

In addition to the 14 critical homophone trials, 14 filler trials with unambiguous targets were constructed. Trials were presented in a fixed random order.

### *Norming*

*Word association norms.* Meaning dominance frequencies were collected in a word association task. Twenty-seven participants provided the association norms and received partial course credit. No participants in this and any of the norming experiments participated in the main experiment. Participants listened to a list of words and, for each word, typed the first related word that came to mind. The stimuli consisted of 148 heterographic and homographic homophones and 80 unambiguous fillers. I selected 14 homophones that elicited word association responses with at least a 19% difference between the dominant and subordinate meaning. Of these 14 homophones, on average, the dominant meaning gathered 79% of the total word association responses, and the subordinate meaning gathered 16% of the total responses. The remaining 5% of the responses had missing values or were unrelated to the two most common meanings of the homophone.

*Picture agreement norms on Actual Referents.* Picture agreement norms confirmed that there was no difference in labeling agreement for the pictures I chose to represent the Actual Referents of the subordinate and dominant meanings of the homophones. Forty-two participants were each presented with a sequence of 200 pictures on a computer screen. Two lists were created such that half of the homophone pictures were of the dominant meaning, and half of the homophone pictures were of the

subordinate meaning. Each participant saw each homophone item once, either in the dominant or subordinate condition. Only one picture appeared on each screen, simultaneously with a box in which they were asked to type the name of the picture of the object represented. Fourteen were pictures of homophones, and 186 were filler pictures with unambiguous labels. Trials were coded as having correct agreement when the response included the homophone in any part of the answer, including misspelled words and plurality differences, but not including synonyms or other names. For example, if the intended label was *flower*, responses such as *purple flower*, *flower petals*, *flowers*, and *flowr* were accepted. However, responses such as *orchid*, *purple bloom*, and *bouquet* were not accepted. The agreement between the participants' responses and the intended labels was 85.5% for the dominant and 81.2% for the subordinate meanings. A t-test indicated no differences in dominance ( $t_2(26) = 0.76, p > .10$ ).

*Picture norms on Shape Competitors.* In choosing the pictures to represent the Shape Competitors, it was not crucial to select pictures with high name agreement, because the relevant factor was shape similarity to a prototypical object representing one of the homophone's meanings. Nonetheless, it would present a confound if a shape competitor picture was likely to be labeled with a name beginning with the same phonemes as the homophone in that particular trial. This is actually a potential weakness for Huettig and Altmann's (2007) competitor condition, described in Chapter 2, because they provided no norms on the shape competitors to ensure that they would not be given a label that overlapped in phonology with the homophone. I worried that, for example, the shape competitor "needle" from their example sentence, would activate *pin*—a phonological competitor for *pen*.

Thus, I collected picture naming data for the shape competitor pictures in an experiment similar to the labeling agreement norms for the Actual Referent pictures. Twenty participants were presented with a sequence of 128 pictures on a computer screen. One list was created with 14 Shape Competitors of the dominant meanings and 14 Shape Competitors of the subordinate meanings of the homophone and 100 filler pictures with unambiguous names. Each participant saw every Shape Competitor once, both in the dominant and subordinate conditions. Only one picture appeared on each screen, simultaneously with a box in which they were asked to type the name of the picture of the object represented. No responses for the Shape Competitor pictures indicated any phonological similarity to the homophone to which the Shape Competitor belonged.

*Picture similarity norms.* Picture similarity norms indicated that the Shape Competitors were in fact similar in shape to the Actual Referents. Twenty-four participants were presented with a series of pictures with questions, such as “How similar in shape is this object to a flower?” Participants were asked to rate on a scale of 1 (not similar) to 7 (very similar) how similar the presented picture was to the object mentioned in the question. Participants’ judgments may also have been influenced by other perceptual variables, such as color and texture, but I explicitly avoided pictures with any conceptual or instrumental relationships to the homophones (Myung, Blumstein, & Sedivy, 2006). In addition to the 28 Shape Competitor trials, there were 25 filler trials in which participants were asked to evaluate the shape similarity of a picture to a concept judged to be either related or unrelated in shape. Participants rated every Shape Competitor once. The mean ratings for shape-similarity were 4.84 and 5.76 for dominant and subordinate Shape Competitor, respectively. A mixed model treating dominance

(dominant or subordinate) as a fixed factor and participants and items as random factors revealed that dominant Shape Competitors were judged less similar in shape to the Actual Referents than subordinate Shape Competitors, so any looks to dominant Shape Competitors cannot be due to higher similarity of those items to the Actual Referents ( $F(1,645) = 63.05, p < .001$ ).

*Picture saliency norms.* Picture saliency norms were conducted to evaluate any difference in saliency among the critical pictures. These norms were collected for all 16 critical trials used in Experiment 2, however only the 14 trials relevant to Experiment 1 are reported here. Thirty-five participants were asked to view pictures silently on the computer screen while a head-mounted eye-tracker monitored their eye movements. Two display conditions were created such that half the participants saw the dominant Actual Referents and subordinate Shape Competitors, and the other half saw the subordinate Actual Referents and the dominant Shape Competitors. On each trial, four pictures appeared on the screen for 5 seconds, and a drift correction procedure was conducted between every trial. The sets of four pictures were the same as in Experiment 1. The critical trials and 28 filler trials were presented in a random order.

The dwell time percentages for each object type in the Dominant-Actual display condition were the following: Actual Referent: 19.1%, Shape Competitor: 20.1%, Filler Objects: 18.7%. Subordinate-Actual display: Actual Referent: 21.2%, Shape Competitor: 18.9%, Filler Objects: 18.5%. To evaluate the effects of display condition on each of the object types (Actual Referent, Shape Competitor, or Filler), mixed models treating display condition (Dominant-Actual or Subordinate-Actual) as a fixed factor and participants and items as random factors were performed. There were no effects of

display condition for any object type (all  $F < 1$ ). In order to evaluate whether the Shape Competitors had any advantage over Fillers in the different display conditions, a mixed model treating object type (Shape Competitor or Filler) and display condition (Dominant-Actual or Subordinate-Actual) as fixed factors and participants and items as random factors found no main effect of object type ( $F(1,1407) = 1.86, p > .10$ ) or display condition ( $F < 1$ ), and no interaction ( $F < 1$ ). Thus, there were no advantages in saliency for pictures representing the dominant meaning over pictures representing the subordinate meaning, nor for Shape Competitors over Filler Objects.

### *Procedure and Equipment*

The auditory sentences and their corresponding slides were presented in a fixed random order. There were four practice trials before the experimental trials began. Eye position was recorded as participants listened to the sentences, using an ISCAN© Head-mounted Eye Tracking System. The eye and scene cameras were mounted on a headgear, with a sampling rate of 120 Hz.

Participants were seated at approximately 24 inches from the screen. The visual angle from the fixation cross to the pictures was approximately 9 degrees. The auditory and visual stimuli were presented using E-Prime software. Participants heard these instructions:

*At the beginning of each trial, you will see a cross in the center of the screen. Surrounding the cross, there will be four pictures. You will hear instructions that will ask you to look at the cross and then point to objects on the screen.*

Before the practice trials, a six-point calibration slide was presented. On each trial, participants were presented with a fixation slide simultaneously with auditory sentence instructions. At 3000 ms after sentence onset, the four-picture slide appeared

simultaneously with the onset of the critical homophone. The experimenters used the scene camera screen to verify whether or not the participant was accurately pointing to the correct targets. The participants were asked to point to the objects manually with a pointer, not a computer mouse, as the hardware did not allow a mouse to be used by the participant. Between each trial, there was an additional six-point calibration slide. If four out of six points were not accurately calibrated, recalibration was performed. The entire experiment lasted less than thirty minutes.

The data were collected and organized using PRZ analysis software provided by ISCAN©.

### *3.1.2 Results*

As noted above, there were two critical pictures on each trial: the Actual Referent and the Shape Competitor. The data for one item were omitted from all analyses, because the subordinate meaning was inadvertently presented in the Dominant-Actual display. Four eye movement measures were analyzed:

- (1) First run dwell time on each of the critical pictures and filler objects
- (2) Visual bias towards shape competitors, measured by log gaze probability ratios to Shape Competitor and Filler Objects from target word onset until 1000 ms after target onset
- (3) Latency of the first look to the critical picture after target onset
- (4) Number of trials with at least one look to the Shape Competitor

Figure 4. Experiment 1 time course of probability of fixations on critical pictures and fillers at each 100 ms interval from homophone target onset for Dominant-Actual (represented with squares) and Subordinate-Actual (represented with triangles) display conditions. The first interval is 0-99 ms after target onset.

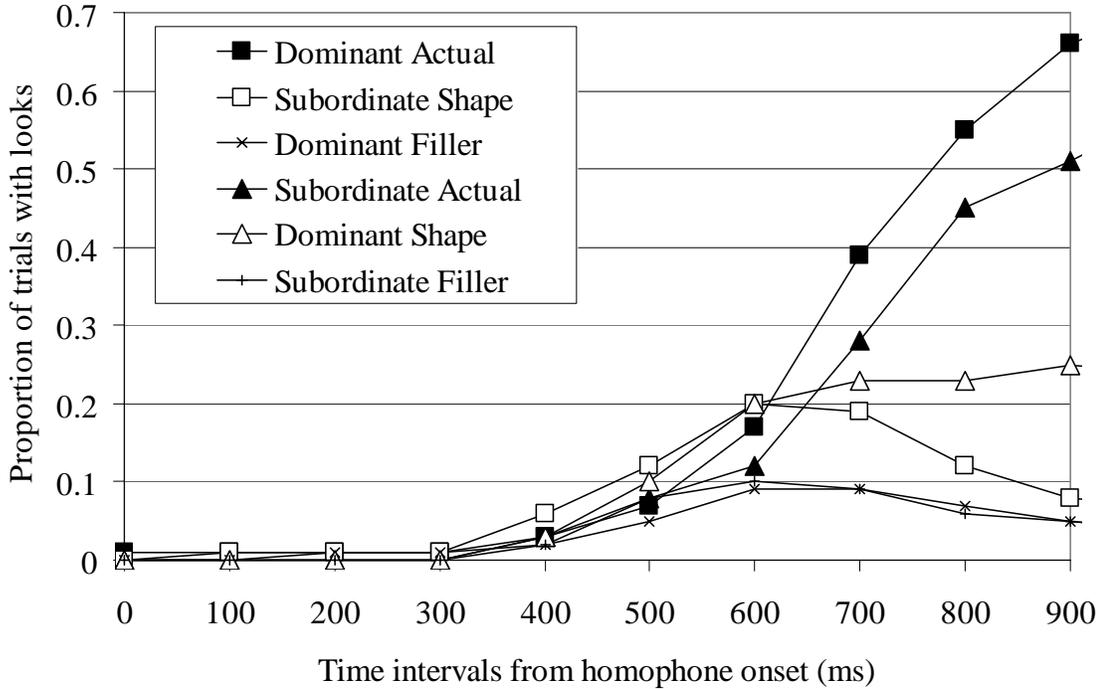


Figure 4 presents the proportion of looks to all four types of critical pictures during each 100 ms interval after homophone onset, for both display conditions. From 0 to 399 ms, participants were not looking at any critical pictures 99% of the time. Beginning at 400 ms, participants started fixating the critical pictures. The dominant Actual Referents appeared to have attracted more looks over time than the subordinate Actual Referents, revealing a relative dominance effect. Looks to Shape Competitors appeared to increase at the same time as the Actual Referents, with dominant Shape Competitors attracting more looks than subordinate Shape Competitors. Looks to the subordinate Shape Competitors decreased starting around 700 ms.

### *First Run Dwell Time*

First run dwell time was analyzed in order to evaluate initial processing time for each of the fixated objects (as in Arai, Van Gompel, & Scheepers, 2007). First run dwell time was defined as the first and all consecutive fixations on an object until another object or background was fixated. To maximize the likelihood that there would be at least one fixation on all four pictures for most trials, I searched for fixations during a large time window, 5 seconds following target onset. The mean first run dwell times for the critical objects in milliseconds, with standard errors in parentheses, were as follows. Dominant-Actual display: Actual Referent: 950(35), Shape Competitor: 174(15), Filler Objects: 134(7). Subordinate-Actual display: Actual Referent: 872(38), Shape Competitor: 360(36), Filler Objects: 164(12).

In order to determine whether the second meaning of the homophones was activated at above chance levels, first run dwell times to the Shape Competitors were compared to the Filler Objects. A mixed model treating display condition (Dominant-Actual or Subordinate-Actual) and object type (Shape Competitor or Filler) as fixed factors and participants and items as random factors was performed. There was a main effect of object type ( $F(1,359) = 30.60, p < .001$ ), indicating that the Shape Competitors had longer first run dwell times than Fillers. There was also a main effect of display condition ( $F(1,34) = 10.19, p < .01$ ). There was also an interaction between display condition and object type ( $F(1,359) = 6.26, p < .05$ ), indicating that the difference in dwell time between dominant Shape Competitors and Fillers was larger than the difference between subordinate Shape Competitors and Fillers. Paired comparisons indicated that for the Dominant-Actual display conditions, subordinate Shape Competitors had

marginally significant longer first run dwell times than Fillers Objects ( $F(1,362) = 3.45, p < .10$ ). For the Subordinate-Actual display, dominant Shape Competitors had fully significant longer first run dwell times than Fillers Objects ( $F(1,351) = 46.88, p < .001$ ). These findings suggest that both the dominant and subordinate meanings, represented by the Shape Competitors, were activated at levels higher than chance. This is not surprising, given the neutral linguistic context and the results of Huettig and Altmann (2007), but it demonstrates activation of the subordinate meaning of a homophone even when a subordinate referent is not viewed prior to homophone onset.

Display condition effects on the first run dwell times to Actual Referents and Shape Competitors were each examined using a mixed model treating Display Condition as a fixed factor and participants and items as random factors. There was no effect of Display Condition on Actual Referents ( $F(1,27) = 1.09, p > .10$ ). There was however a marginal effect of Display Condition on Shape Competitors ( $F(1,34) = 3.64, p < .10$ ), revealing a dominance effect on Shape Competitors.

#### *Visual Bias towards Shape Competitors*

To evaluate the time course of activation of the second meaning of ambiguous words, visual bias towards the Shape Competitor compared to the Filler Objects was analyzed in 100 ms intervals from target word onset until 1 second after target onset. As per Arai et al. (2007), log gaze proportions were used in order to circumvent problems of interdependence between looks to pictures. If an Actual Referent is fixated 70% of the time in condition A and 50% in condition B, the Shape Competitor automatically has a lower chance of being fixated in the condition A than B, purely based on being paired with an object that attracts more fixations. Thus, it is not appropriate to compare absolute

proportions to different pictures on the same trial. Log gaze proportions provide a measure of bias towards the Shape Competitor that is independent of the proportion of fixations to the Actual Referent, providing an appropriate measure of higher-than-chance activation. Because Filler Objects should not attract fixations when the homophone is spoken, and only be fixated by chance, any bias towards Shape Competitors over Filler Objects would indicate preferential processing of the dominant meaning.

I used Arai et al.'s (2007) formula for log ratios to evaluate the strength of visual bias towards Shape Competitors:

$$\ln(P(\text{Shape Competitor})/P(\text{Filler Objects}))$$

$P(\text{Shape Competitor})$  is the likelihood of fixating the Shape Competitor during the 100 ms interval, and  $P(\text{Filler Objects})$  is the likelihood of fixating a Filler Object during the 100 ms interval. Using the log of the ratio of likelihoods yields a number that is either 0 (equal bias), positive (indicating a Shape Competitor visual bias) or negative (indicating a Filler Object visual bias). Note that there are missing values for several log-ratio values due to zero values at the early bins: no ratio can be determined using zero as a denominator, nor a log value for zero. Also due to missing values, statistics could be computed starting only from the 400 ms interval.

Mixed models treating the log-ratios (log-ratios vs. 0) and display condition (Dominant-Actual or Subordinate-Actual) as fixed factors and either participants or items as random factors were performed for each 100 ms interval from 400 ms until 1000 ms after target onset, as shown in Table 1. The degrees of freedom change for the different analyses based on the number of zero probabilities on a trial by participants or items. These differences in degrees of freedom across intervals affect the strength of the F

values, such that lower means can produce more significant F values if they have more degrees of freedom.

Table 1

*Experiment 1 log ratios of visual bias towards shape competitors over fillers to zero, including mixed model effects in 100 ms time intervals from homophone onset*

Bin	Log-ratio by Display Type		Log-ratio Main Effects			
	Dominant Actual	Subordinate Actual	dfs	F <sub>1</sub>	dfs	F <sub>2</sub>
400	1.01	0.00	1,4	38.24**	1,4	7.20 <sup>m</sup>
500	0.79	0.07	1,15	18.88**	1,30	12.09**
600	0.72	0.19	1,18	15.21**	1,20	20.20***
700	0.69	1.07	1,23	27.02***	1,23	28.08***
800	0.31	2.00	1,19	31.46***	1,19	15.87**
900	-0.17	2.17	1,17	30.09***	1,13	16.69**

<sup>m</sup> $p < .10$ , \* $p < .05$ , \*\* $p < .01$ , \*\*\* $p < .001$

The mixed model found main effects of the log-ratio starting at the 400 interval, significant by participants and marginal by items, and was fully significant from 500 through 1000 ms. This indicates that a visual bias towards the Shape Competitor, compared to Filler Objects, was evident for both the dominant and subordinate meanings. Interactions of log-ratio with display type appeared at the 800 and 900 ms interval (800 ms:  $F_1(1,19) = 7.68$ ,  $p < .05$ ,  $F_2(1,19) = 10.93$ ,  $p < .01$ ; 900 ms:  $F_1(1,17) = 15.96$ ,  $p < .01$ ,  $F_2(1,13) = 5.07$ ,  $p < .05$ ), indicating a stronger visual bias towards the dominant Shape Competitor than the subordinate Shape Competitor. In sum, the activation of the second meaning, as indexed by visual bias towards the Shape Competitor, compared to Filler Objects, was evident for both the dominant and subordinate meanings at early time

frames. The likelihood of fixating the Shape Competitors in a given interval depended on whether it represented the dominant meaning or the subordinate meaning.

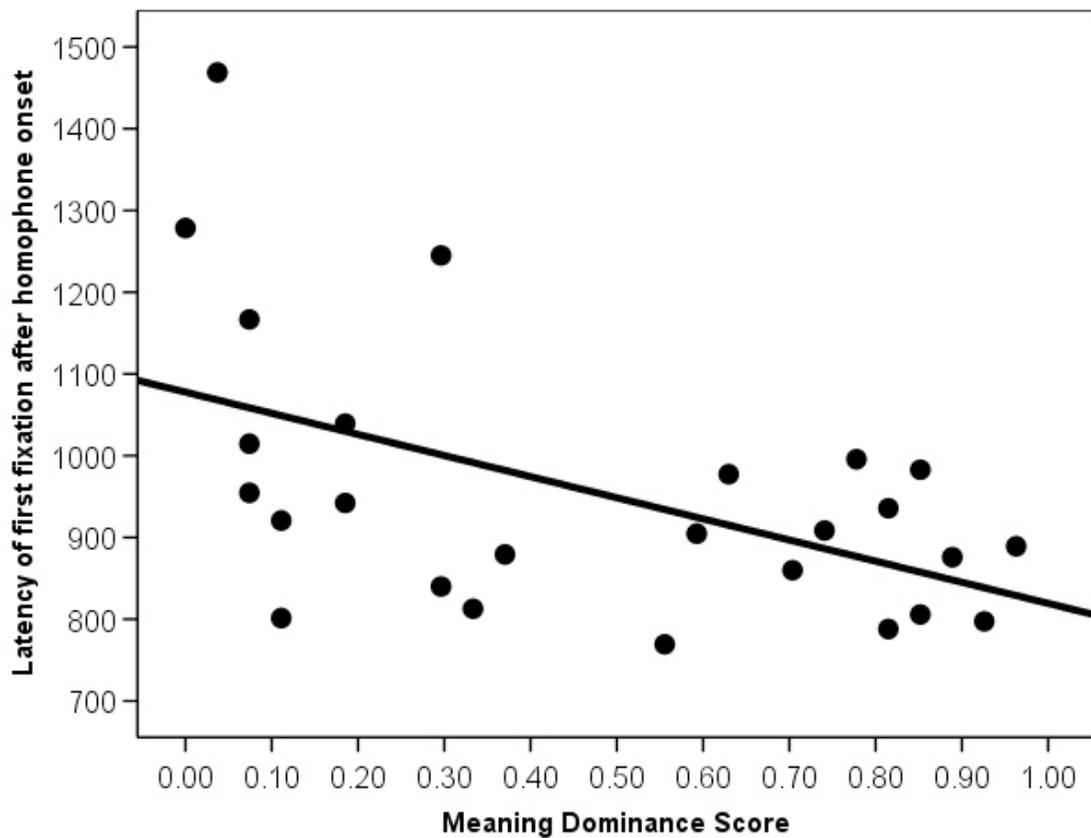
These results show that multiple meanings of a word were activated after hearing the ambiguous word, because Shape Competitors attracted a higher proportion of fixations than Filler Objects. Even when there was a matching referent to the homophone on the visual display, alternative meanings of a word had an effect on eye movements, directing attention towards the Shape Competitor of the alternate meaning. Furthermore, relative dominance influenced the degree of activation of the Shape Competitors, such that dominant Shape Competitors were looked at comparatively more than the subordinate Shape Competitors.

#### *Latency of First Fixation*

The latency of the first look to a critical picture after homophone onset was examined as a function of each homophone's relative dominance in order to evaluate a more detailed correlation between relative meaning dominance and eye movements. Trials that had latencies of above 3 standard deviations were not included, which was 2.6% of trials. The average length of the spoken homophone was 527 ms, and the amount of time it takes to plan and execute an eye movement is approximately 200 ms. The mean latency of first looks to the Actual Referent pictures after homophone onset was 956 ms, i.e., on average, a fixation to an Actual Referent was planned within 250 ms of homophone offset. The mean latency of first looks to the Shape Competitor pictures after homophone onset was 737 ms, indicating that many of these fixations were planned prior to homophone offset. The latency to Shape Competitors may have been faster than to Actual Referents because Shape Competitors did not require fixations, while Actual

Referents were required to be fixated in order to complete the trial as directed. Thus, Shape Competitors, if fixated at all, were generally not fixated late in the trial. As shown in Figure 5, meaning dominance inversely affected latency of first look to the Actual Referent picture: as dominance increased, latency decreased ( $r(26) = -.52, p < .01$ ) ( $F_2(1,24) = 8.64, p < .01$ ). The analogous correlation was not found for Shape Competitor pictures, suggesting that the meaning dominance was more directly related to looking latency for the Actual Referent than for the Shape Competitor.

*Figure 5.* Experiment 1 regression of average latency of first look to the Actual Referent picture from trial onset with relative meaning dominance. Shorter latencies were observed for more dominant meanings.



### *Probability of Fixation*

The proportion of trials in which participants made at least one look to a Shape Competitor within 1000 ms of homophone onset was 0.51 and 0.27 for dominant and subordinate Shape Competitor pictures, respectively. A mixed model treating dominance (dominant or subordinate) as a fixed factor and participants and items as random factors confirmed that there were more trials with looks to the dominant Shape Competitors than the subordinate Shape Competitors ( $F(1,323) = 20.52, p < .001$ ). This was predicted by the relative dominance hypothesis, in which dominant meanings of an ambiguous word are more highly activated than subordinate meanings.

### *3.1.3 Discussion*

In Experiment 1, as the spoken homophone unfolded in a neutral linguistic context, participants accessed multiple meanings, and relative activation of the two meanings was measured by observing the proportions of looks to pictures corresponding to each meaning of the homophone. One meaning's activation was measured by looks to a picture depicting an actual referent, and the alternative meaning's activation was measured by looks to a visual shape competitor of that meaning's prototypical referent. Recall that Huettig and Altmann (2007) also found activation of both subordinate and dominant meanings in neutral context, but it was unclear to what extent the fixation patterns were dependent upon visual preview of the potential referents. I find it particularly striking that, in the current experiment, the subordinate meaning of the homograph was activated (based on above chance looks to the Shape Competitor) even when an Actual Referent for the dominant meaning was pictured.

The design of this experiment also allowed us to investigate the influence of meaning frequency on fixation patterns. Crucially, I found dominance effects in the proportion of looks to both Actual Referents and Shape Competitors. While neither dominance effect is particularly surprising given the ubiquity of frequency effects in neutral contexts, it was important to demonstrate that dominance effects could be found with Shape Competitors when an Actual Referent was simultaneously pictured. Even though there was a pictured target consistent with the spoken input, activation of other meanings of the homophone directed looks to other objects on the screen, namely the shape competitors of the alternative meaning.

Because the visual context was presented simultaneously with the spoken homophone, there was no previous visual or linguistic context to bias the meaning of the homophone. Thus, meaning frequency was the only available influence on initial spoken word recognition in this paradigm. Nonetheless, as the visual context was integrated with the spoken input, effects of the visual display on word recognition were observed. That is, initially, looks towards the Actual Referent and the Shape Competitor of the alternative meaning of the homophone increased in a similar fashion, but after 700 ms, the activation of the alternative meaning decreased, reflecting resolution of the homophone toward the pictured meaning.

### 3.2 Experiment 2: Context Effects on Homophones

Whereas the primary focus in the first experiment was on meaning dominance effects, the primary focus in Experiment 2 was on sentence context effects. The Reordered Access and Selective Access accounts of ambiguity resolution differ in how a strong subordinate-biasing context affects the pattern of activation of multiple meanings

of homophones, so I manipulated whether subordinate-biasing sentence context before the homophone was heard. Participants heard homophones in either Neutral or Subordinate-Biased contexts (e.g., Neutral: *Jenny looked at the table and was surprised to see the flower/flour*; Subordinate-Biased: *The baker took out the necessary ingredients, like milk, eggs, and flour*). At homophone onset, four pictures appeared: a subordinate meaning Actual Referent (*flour*), a dominant meaning Shape Competitor (lollipop, for *flower*), and two unrelated pictures. The Shape Competitor was used to index subliminal activation of the dominant meaning.

*Reordered Access* theories would predict that the dominant meaning of the homophone will still be activated even under strong subordinate-biasing context because of the high frequency of the dominant meaning (Duffy et al., 1988, 2001). This theory would also predict changes in level of activation of the subordinate meaning across context conditions, but no change in the initial activation level of the dominant meaning. While the dominant meaning must eventually be discarded because it is contextually inappropriate, its activation should not be affected by subordinate-biasing contexts. *Selective Access* theories would predict that activation of the dominant meaning is a function of contextual strength, so the dominant meaning should be strongly activated in the neutral context, but not activated at all in the strongly subordinate-biased context (Martin et al., 1999).

By comparing both Neutral and Subordinate-Biased Contexts, I could measure the influence of context on activation of both the appropriate and the inappropriate meanings of the homophone. As in Experiment 1, none of the dominant Shape Competitors overlapped in phonology with the spoken referent names, so any activation of the Shape

Competitor from the spoken input indicated activation of the dominant meaning of the homophone. The activation of the dominant meaning of the homophone was measured by comparing looks to the Shape Competitor picture with looks to any of the Filler Objects (by chance). If Shape Competitors of the dominant homophone meaning attracted more looks than chance in either the Neutral Context, Subordinate-Biased Context, or both, multiple meanings were accessed.

### *3.2.1 Methods*

#### *Participants*

Thirty undergraduates at the University of Michigan participated in this experiment for course credit in an Introductory Psychology class or were paid for participation. All participants were native speakers of English and had normal or corrected vision.

#### *Materials*

Sixteen homophones were selected with the criteria as in Experiment 1. The 14 homophones from Experiment 1 were included, and two additional homophones were added in order to increase statistical power (see Appendix B).

In contrast to Experiment 1, only the subordinate meaning of the homophone was ever pictured as the Actual Referent, and it always appeared with an object that was similar in shape to the dominant meaning of the homophone (Shape Competitor). The norms used to assess shape similarity are described below.

Visual stimuli consisted of four pictures arranged in a 3x3 grid on a white background with a fixation cross in the center for each critical trial. The critical pictures were all full-color realistic images selected from an online searchable database of images

(Google, 2004). The pictures appeared in the upper left, upper right, lower left, or lower right area of the grid, arranged so that the Actual Referent appeared in each corner an equal number of times for every participant. The Shape Competitor also appeared in each corner an equal number of times for every participant. The two remaining corners contained filler pictures of objects with unambiguous names that did not begin with the same phonemes as the critical homophone and were not similar in shape to the critical pictures.

Two linguistic context conditions were created for each of the sixteen homophones (see Appendix C). In the Subordinate-Biased Context condition, participants heard a sentence context that constrained the homophone toward its subordinate meaning (e.g., *The baker had agreed to make several pies for a large event today, so he started by taking out necessary ingredients, like milk, eggs, and flour*). No lexical associates were used in the sentence, in order to exclude bottom-up lexical priming as a factor in activation of either meaning of the homophone. In the Neutral Context condition, participants heard a sentence context in which both meanings of the homophone were very plausible (e.g., *As Jenny walked into the house after school, she looked at the table and was surprised to see the flower/flour*). The norms for meaning bias of sentence contexts appear below. Linguistic context condition was varied between participants because the probability of looks to the Shape Competitor in the Subordinate-Biased Context might be quite low, and I wanted to maximize statistical power for evaluating the hypothesis that the Shape Competitor was nonetheless activated at greater than chance levels. Each participant was randomly assigned to one of the two linguistic context conditions. The auditory stimuli were recorded by a female speaker.

In addition to the 16 critical homophone trials, 28 filler trials with unambiguous targets were constructed. Trials were presented in a randomized order for each participant.

### *Norming*

The picture agreement and similarity norms were run again for Experiment 2 in order to incorporate the 2 items which were not included in Experiment 1. In order to test the contextual strength of the sentences used in Experiment 2, meaning bias norms were also conducted.

*Picture agreement norms on Shape Competitors.* In order to ensure that the Shape Competitor pictures did not activate any lexical items beginning with the same phonemes as the homophones, I collected data from a picture naming agreement task. Twenty-three participants were presented a sequence of 132 pictures on a computer screen. The list was created such that Shape Competitors of the dominant meaning of the 16 homophones were presented randomly with 116 filler pictures with unambiguous names. Each participant saw every Shape Competitor once. Only one picture appeared on each screen, simultaneously with a box in which they were asked to type the name of the picture of the object represented. No responses for the Shape Competitor pictures indicated any phonologically similarity to the actual homophone.

*Picture similarity norms.* Picture similarity norms indicated that the Shape Competitors were in fact similar in shape to the Actual Referents. I collected data from a picture similarity task. Twenty-three participants who participated in the picture naming norms were presented with a series of pictures with questions, such as “How similar in shape is this object to a flower?” Participants were asked to rate on a scale of 1 (not

similar) to 7 (very similar) how similar the presented picture was to the object mentioned in the question. The 16 Shape Competitor pictures of the dominant homophone meaning of were tested according to their similarity to the homophones, along with 58 filler ratings to unrelated objects, which varied in visual form similarity. The Shape Competitor pictures were presented along with a question asking how similar that object is to the actual homophone object. Participants rated every Shape Competitor once. The mean rating for shape-similarity was 5.25, which indicates high similarity of visual form to the actual dominant homophone referent.

*Meaning bias norms.* Meaning bias norms indicated that the Subordinate-Biased Context sentences indeed biased only the subordinate meaning of the homophone, and that the Neutral Context did not favor one meaning of the homophone. I collected data from a sentence bias rating task. Twenty participants were presented with a series of auditory sentences with questions, such as “Was the sentence you just heard referring to a flower or flour?” Participants were asked to rate on a scale of 1 (dominant) to 9 (subordinate) the likelihood of two different interpretations of the object mentioned in the sentence. Participants rated every homophone twice, with all 16 Neutral Context sentences rated before the 16 Subordinate-Biased Context sentences, dispersed randomly among with 40 filler ratings to unrelated sentences. The mean ratings for the subordinate meaning were 8.85 and 4.98 for the Subordinate-Biased and Neutral Context sentences, respectively. These bias ratings were converted in the same manner as Martin et al. (1999) in order to test whether the Subordinate-Biased and Neutral distributions overlapped. The scale was converted to represent the strength of deviation from the center of the scale: 0 represented ambiguity and 4 represented a strong bias. The contexts

had the following scores: Subordinate-Biased:  $M = 3.85$ ,  $SD = 0.39$ ; Neutral:  $M = -0.02$ ;  $SD = 1.42$ . Compared to the strongly biasing contexts in Martin et al. (1999), the Subordinate-Biased contexts were similarly biased or stronger.

*Picture saliency norms.* Picture saliency norms were conducted to evaluate any difference in saliency among the critical pictures. These norms were collected for all 16 critical trials. The procedure for the saliency norms is reported above in Experiment 1. Only data from the relevant Subordinate-Actual display are reported here. The dwell time percentages for each critical picture as follows: Actual Referents: 21.0%, Shape Competitors: 18.8%, Filler Objects: 18.8%. A mixed model treating object type (Shape Competitor or Filler) as a fixed factor and participants and items as random factors found no advantage in saliency for Shape Competitors over Filler Objects ( $F < 1$ ).

#### *Procedure and Equipment*

Experiment 2 differs from Experiment 1 in the eye-tracking system used. Experiment 2 employs an Eyelink II head-mounted binocular eye tracking device. As in Experiment 1, the eye cameras were mounted on headgear, but Experiment 2 used a sampling rate of 500 Hz. In contrast to Experiment 1, the order of the auditory sentences and their corresponding slides was randomized for each participant. Also, the participants performed a task of clicking and moving an object with the computer mouse, in the tradition of Allopenna et al. (1998).

Participants were seated at approximately 24 inches from the screen. The distance from the fixation cross to the center of the pictures was approximately 7.5 degrees. The auditory and visual stimuli were presented using SR Research Experiment Builder software. Participants read these instructions:

*In this experiment, you will hear a sentence. At the end of the sentence, you will see four objects on the screen. Your task is to click on the object that matches the last word of the sentence you just heard and drag it to the center of the screen. For example, if you heard "The cat was scared of the dog, so it ran under the table", you would click on the TABLE and drag it to the center of the screen. You will also have a comprehension question after every sentence. Please say your answer (YES or NO) out loud.*

Before the experiment began, the experimenter performed a calibration procedure.

Before each trial, a drift correction procedure was performed. On each trial, participants looked at a fixation cross while listening to the sentence. The pictures appeared simultaneously at target word onset. The entire experiment lasted fewer than thirty minutes.

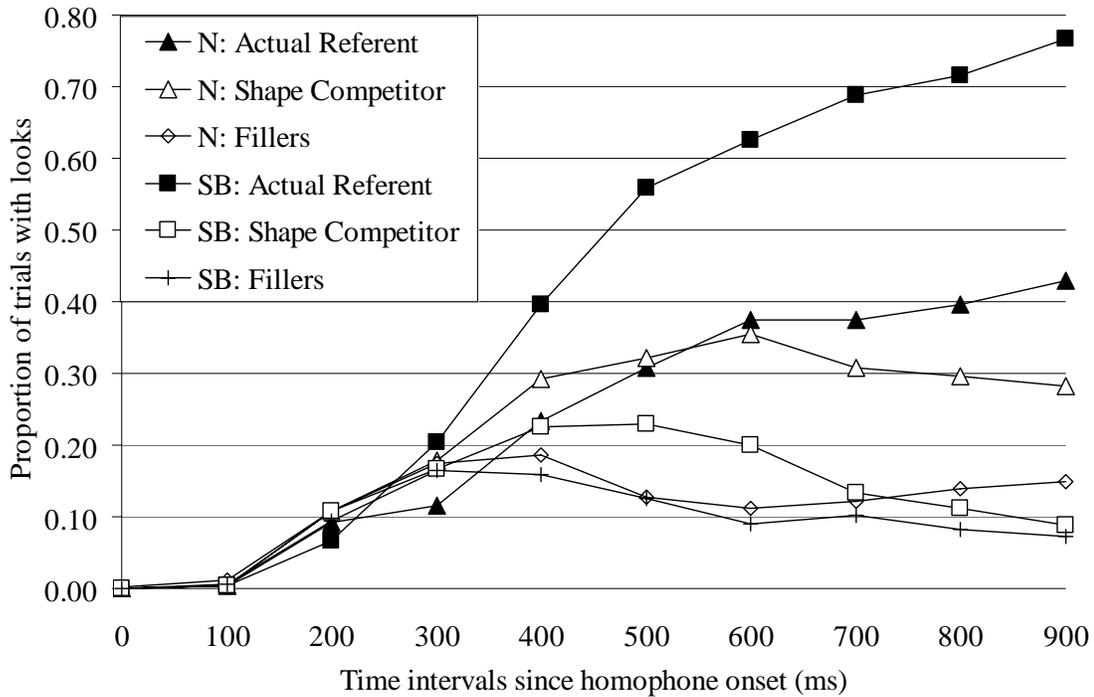
The data were collected and organized using SR Research Experiment Builder and Data viewer software.

### 3.2.2 Results

The participants responded correctly to the comprehension questions 92.9% of the time. As in Experiment 1, there were two critical pictures on each trial, the Actual Referent and the Shape Competitor. The three eye movement measures analyzed include the following:

- (1) Average proportion of looks to critical items from target word onset until 1000 ms after target onset
- (2) First run dwell time on each of the critical pictures
- (3) Visual bias towards Shape Competitors, measured by log gaze probability ratios to Shape Competitor and Filler Objects from target word onset until 1000 ms after target onset

Figure 6. Experiment 2 time course of probability of fixations on critical pictures and fillers at each 100 ms interval from homophone target onset, with Neutral Context (N) represented with triangles and Subordinate-Biased Context (SB) represented with squares. The first interval is 0-99 ms after target onset.



#### *Proportion of Fixations over Time*

Figure 6 presents the proportion of looks to critical pictures and fillers during each 100 ms interval after homophone onset, for both context conditions. The effects of context appeared to be quite large, with Subordinate-Biased Context both increasing fixations to the Actual Referent and decreasing fixations to the Shape Competitor for the dominant meaning. Clearly, the dominant meaning was strongly activated in the Neutral Context, as evidenced by many fixations on the Shape Competitor. Less clear, is whether the dominant meaning was still partially activated in the Subordinate-Biased Context.

The proportion of looks to critical objects seems to have risen more slowly in Experiment 1 (500ms) than in Experiment 2 (300ms). Several factors may have

contributed to this difference in timing, and it is most likely that a combination of factors caused these differences. First, differences in the display types between the two experiments can explain some of the timing difference. In Experiment 1, the pictured objects were located in one of the four large quadrants of the screen, but varied in size and location within the quadrants. In contrast, in Experiment 2, a 3x3 grid in the center of the screen was used on every trial, with a picture in each corner of the grid. The size of each picture was adjusted to be as large as possible, while still fitting within the boundaries of the appropriate square. Thus, the location and size of the objects was more constrained in Experiment 2, whereas the pictures tended to be larger, more irregular, and farther from the fixation cross in Experiment 1. This difference in the visual layout of the screen may have made it easier in Experiment 2 to quickly assess the content of each picture and plan a saccade to the appropriate picture. Secondly, the more constraining sentence contexts in Experiment 2 may have contributed to differences in time course. Even the Neutral Context sentences in Experiment 2 semantically constrained the interpretation of the homophone prior to homophone onset, compared to unvarying spoken instructions in Experiment 1. This may have lead to faster lexical access times, which in turn would lead to earlier fixations on the pictures (In contrast, in both experiments, predictive processing *due to the visual display* is not likely because the pictures did not appear until homophone onset). Lastly, differences in tasks, instructions and equipment between the two experiments may have also played a role. In particular, Experiment 1 employed a pointing task, while Experiment 2 required participants to use the computer mouse, which may have made the participants more attentive to the mouse pointer and other objects on the screen.

### *Proportion of looks to critical items*

To evaluate the time course of the influence of biasing context, I analyzed the proportion of looks to each critical picture in 100 ms intervals from target word onset. First, I contrasted looks to the Actual Referent during Subordinate-Biased and Neutral Contexts using a mixed model that treated context condition (Neutral or Subordinate-Biased) as a fixed factor and participants and items as random factors. Starting at 300 ms, the Subordinate-Biased Context increased looks to the Actual Referents compared to the Neutral Context ( $F(1,463) = 7.35, p < .01$ ), continuing to be fully significant through 1000 ms.

The context also influenced the probability of looks to the Shape Competitors. A mixed model that treated context condition (Neutral or Subordinate-Biased) as a fixed factor and participants and items as random factors found a marginal effect at 400 ms ( $F(1,463) = 2.98, p < .10$ ), and a fully significant context effect from 500 ms ( $F(1,463) = 5.57, p < .05$ ), and continued to be fully significant through 1000 ms. These findings indicated that at early time intervals, the Subordinate-Biased Context both increased activation of the subordinate meaning and decreased activation of the dominate meaning, relative to a Neutral Context.

### *First Run Dwell Time*

First run dwell time was analyzed in order to evaluate initial processing time for each of the fixated objects. The mean first run dwell times for the critical objects in the Neutral Context condition in milliseconds, with standard errors in parentheses, were as follows: Actual Referent: 590(13), Shape Competitor: 246(6), Filler Objects: 205(3). The

means for the Subordinate-Biased Context condition were as follows: Actual Referent: 706(15), Shape Competitor: 228(9), Filler Objects: 192(3).

In order to determine whether the dominant meaning of the homophone was activated at above chance levels, first run dwell times on the Shape Competitors were compared to mean first run dwell times on the unrelated Filler Objects. A mixed model treating context condition (Neutral or Subordinate-Biased) and object type (Shape Competitor or Filler) as fixed factors and participants and items as random factors was performed. There was no main effect of context condition ( $F(1,31) = 2.368, p > .10$ ). There was a main effect of object type ( $F(1,982) = 104.45, p < .001$ ), indicating that the Shape Competitors had longer first run dwell times than Fillers. Crucially, there was no interaction ( $F < 1$ ), indicating that there was no influence of context condition on the dwell times on the Shape Competitor compared to Filler Objects. Paired comparisons indicated that for both context conditions, subordinate Shape Competitors had longer first run dwell times than Fillers (Neutral:  $F(1,973) = 73.62, p < .001$ ; Subordinate-Biased:  $F(1,983) = 37.65, p < .001$ ). These findings suggest that the dominant meaning, represented by the Shape Competitor, was activated at levels higher than chance, even during the Subordinate-Biased Context.

Contextual bias effects on the first run dwell times to Actual Referents and Shape Competitors were each examined using a mixed model treating context condition (Neutral or Subordinate-Biased) as a fixed factor and participants and items as random factors. There was an effect of context type on Actual Referents ( $F(1,28) = 10.14, p < .01$ ), such that the Actual Referent in the Subordinate-Biased Context condition was fixated longer than in the Neutral Context. This effect confirms that the Subordinate-

Biasing Context boosted activation of the appropriate subordinate meaning. There was however no context effect on Shape Competitors ( $F(1,28) = 1.68, p > .10$ ).

#### *Visual Bias of Shape Competitors*

As another test of whether the dominant homophone meaning was activated in the Subordinate-Biased Context, I compared the observed proportion of looks to the proportion that would be expected on the basis of chance alone. To evaluate this activation, I used log gaze ratios as a measure of visual bias to the Shape Competitors compared to Filler Objects. Log-gaze ratios provide a measure of bias towards the dominant meaning compared to Filler Objects that is independent from the level of activation of the subordinate meaning. If Shape Competitors are activated more than Filler Objects, this would be evidence for higher activation than expected by chance. Due to missing values, statistics could be computed starting only from the 200 ms interval.

Table 2

*Experiment 2 log ratios of visual bias towards shape competitors over fillers to zero, including mixed model effects in 100 ms time intervals from homophone onset*

bin	Log-ratios by Context Type		Log-ratio Main Effects			
	Neutral	Subordinate Biased	dfs	F <sub>1</sub>	dfs	F <sub>2</sub>
200	0.00	0.14	1,21	2.50	1,38	6.84*
300	0.02	0.01		<1		<1
400	0.45	0.35	1,27	26.21***	1,56	6.27*
500	0.93	0.61	1,27	49.52***	1,56	16.98***
600	1.15	0.80	1,26	63.22***	1,52	30.84***
700	0.94	0.27	1,25	15.25**	1,25	13.56**
800	0.75	0.30	1,23	9.81**	1,24	23.10***
900	0.64	0.18	1,23	6.71*	1,33	12.74**

<sup>m</sup>*p* < .10, \**p* < .05, \*\**p* < .01, \*\*\**p* < .001

Mixed models treating the log-ratios (log-ratios vs. 0) and context condition (Neutral or Subordinate-Biased) as fixed factors and either participants or items as random factors were performed for each 100 ms interval from 200 ms until 1000 ms after target onset, as shown in Table 2. The degrees of freedom change for the different analyses based on the number of zero probabilities on a trial by participants or items. These differences in degrees of freedom across intervals affect the strength of the F values, such that lower means can produce more significant F values if they have more degrees of freedom. There was a main effect of the log-ratios to 0 starting at 200 ms, significant only by items, not by participants. The main effect was significant from 400 until 1000 ms by both participants and items. Dominant meaning activation in the Neutral Context is predicted by both Reordered Access and Selective Access theories, however,

evidence of dominant meaning activation during the strong Subordinate-Biased Context was only predicted by the Reordered Access theory.

Context condition interacted with the log-ratios at 600 ms ( $F_1(1,26) = 3.40, p < .05, F_2(1,52) = 3.88, p < .05$ )<sup>5</sup>, revealing a larger bias in the Neutral Context than the Subordinate-Biasing Context. This indicates that the Subordinate-Biased Context affected the level of activation of the dominant meaning, as represented by the Shape Competitor. Assuming that this effect reflects early lexical processing, and not post-lexical processing, this difference indicates that context did influence the activation level of the dominant meaning. This finding is problematic for a strict version of Reordered Access that assumes that a Subordinate-Biased Context has an effect only on the subordinate meaning, by increasing its initial activation, and leaves the dominant meaning activation unaffected. This finding, however, is consistent with the Selective Access view that strong Subordinate-Biasing Context both increases activation of the subordinate meaning and limits activation of the dominant meaning.

### 3.2.3 Discussion

There are three important findings reported here. First, context influenced the proportion of fixations on the subordinate Actual Referent, starting at 300ms after homophone onset. This finding is consistent with all accounts of the Subordinate Bias Effect, as well as both Reordered and Selective Access. Second, the dominant Shape Competitor attracted more fixations than expected by chance, even in the Subordinate-

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<sup>5</sup> This was a one-tailed comparison. A one-tailed test is appropriate here because subordinate-biasing context is predicted to decrease activation of the dominant meaning, according to Selective Access, while Reordered Access predicts no effect of context on the dominant meaning. A more conservative two-tailed comparison revealed a marginal context effect on the dominant meaning, by both participants and items ( $F_1(1,26) = 3.40, p < .10, F_2(1,52) = 3.88, p < .10$ ). However, the two-tailed comparison was fully significant when we excluded the 3 items whose subordinate-biased and neutral contexts differed by less than 30% in the meaning bias norms of Experiment 2 ( $F_1(1,52) = 10.29, p < .01, F_2(1,36) = 8.49, p < .01$ ).

Biased Context condition. This effect is predicted by competition-based accounts of the Subordinate Bias Effect, Reordered Access, and is consistent with the Huettig and Altmann (2007) findings, but is not consistent with Selective Access accounts.

Third, context influenced the proportion of fixations on the dominant Shape Competitor, beginning 500ms after homophone onset, according to the raw proportion of fixations over time. Using a more stringent test (log ratios), context influenced the amount of bias towards the dominant Shape Competitor, beginning 600ms after homophone onset. The theoretical importance of this finding depends upon whether it reflects contextual modulation over initial access of the dominant meaning, as would be expected under Selective Access, or rapid use of context to select the appropriate meaning, as would be expected under Reordered Access. Average homophone duration was 527 ms, and the amount of time it takes to plan and execute an eye movement is approximately 200 ms, so the linguistic context began to influence looks to the pictured objects prior to homophone offset. Of course, spoken word recognition can occur mid-word in some cases (Marslen-Wilson, 1975; Marslen-Wilson & Tyler, 1975), so the fact that these context effects begin prior to homophone offset is no guarantee that they reflect initial lexical access rather than post-access processes.

One factor that seems to support the Reordered Access account is that the context effects emerged about 200 ms earlier for the contextually supported subordinate Actual Referent than they did for the contextually unsupported dominant Shape Competitor. Reordered Access maintains that, in a Subordinate-Biased Context compared to a Neutral Context, access to the subordinate meaning will be faster. Initial access to the dominant meaning will be unaffected, but once context is used to select the subordinate meaning,

the dominant meaning will become less activated. In this experiment, if looks to the Actual Referent and the Shape Competitor are equally sensitive to activation of the subordinate and dominant meanings, respectively, a different time-course for context effects would indeed be predicted by Reordered Access. Unfortunately, because only the subordinate meaning was actually pictured while the dominant meaning was represented by a Shape Competitor, the implications of this time-course difference are unclear. It is also unclear whether the later context effects for the Shape Competitor are actually late enough to reflect post-access processing.

Another way to gauge the theoretical implications of the contextual modulation of the dominant meaning in this experiment is to compare the time-course of these results with well-known cross-modal priming studies. It is more difficult to compare the time-course of these results with reading studies because the perception of word form and the temporal dynamics of lexical activation are quite different in the written and spoken modalities. The classic experiments that initially established multiple meaning activation presented the target word at homophone *offset* (Swinney, 1979; Tanenhaus et al., 1979). To the extent that the paradigms are comparable, the current experiments tapped lexical processing at a slightly earlier time-point than these experiments, and certainly earlier than cross-modal experiments that delayed presentation of the target word until 200 ms or more after homophone offset, demonstrating that, by that time, a single referent had been selected after initially activating multiple candidates (e.g., Seidenberg et al., 1982).

Another point of comparison is provided by more recent visual world experiments investigating lexical activation. For example, Allopenna et al. (1998) found more fixations to unambiguous referents and phonological cohorts than controls from 300-700

ms after critical word onset. Similarly, Dahan et al. (2001) found more fixations to unambiguous referents and phonological cohorts than controls from 200-500 ms after the critical word onset. These effects occurred before the offset of the spoken target, with eye movements planned almost immediately after target onset. However, in both cases, the spoken input was disambiguated earlier than in the current experiments, which could affect how early the saccades were planned. Also, the pictures were on the screen for several seconds prior to pronunciation of the critical word, which could conceivably allow strategic processing of the visual input, increasing lexical activation prior to integration of the spoken input. At a minimum, free viewing of the pictures before hearing the target word would facilitate saccade planning.

In sum, I cannot completely rule out the possibility that the context effects on the dominant meaning reflect post-access use of context, but taken together with the broader literature, it is most likely that the context modulated the initial activation of the dominant meaning. If so, these findings provide evidence against any theory of lexical ambiguity resolution that maintains that the dominant meaning is always accessed simply based on the strong form-meaning mapping, and not modulated by sentential context. Thus, a strict version of Reordered Access in which only activation of the contextually appropriate meaning is influenced by context, cannot provide an account of this finding.

In short, these data support a version of Reordered Access in which the activation of each of a homophone's meanings is modulated by context very early during lexical access. A strong subordinate bias may both increase the activation of the subordinate meaning and decrease activation of the dominant meaning. For balanced homophones, context may sometimes be strong enough to selectively activate a single meaning.

However, for polarized homophones, the dominant meaning is likely to be somewhat activated, even in strongly subordinate-biased contexts, based solely on the strength of its form-meaning mapping. Although context can have a great influence on activation of each of the homophone meanings, activation of a strongly dominant meaning probably cannot be completely overridden.

CHAPTER 4  
MOTIVATIONAL EFFECTS ON LEXICAL AMBIGUITY RESOLUTION IN  
READING

Experiment 2 and previous research investigating context effects on lexical ambiguity resolution have shown evidence that dominant meanings remain active during subordinate-biased contexts, which supports Reordered Access and is inconsistent with Selective Access (Duffy et al., 1998, 2001; Martin et al., 1999). However, to make the case that Reordered Access, rather than Selective Access, is supported, one relies on the assumption that the subordinate-biased context has been fully understood. In practice, this may not be the case. Participants could fail to sufficiently attend to and comprehend the sentence contexts, even if the context itself is strongly biasing to the subordinate meaning. This situation could inadvertently allow dominant meaning activation during subordinate-biased contexts.

One indication that participants may not fully attend to and understand the sentence context is that participants are typically unpaid, receiving credit for participation no matter their effort, so there is no incentive to perform optimally in an experiment. Thus, the participants lack motivation to perform well. If motivation were increased, it is possible that attention and comprehension of the sentence context may also increase, which would remove the confound of inattention to the subordinate-biasing context.

Previous research has indicated that variables such as monetary incentive, feedback, and supervision may increase motivation in an experimental task by increasing effort, and thus, performance level (Hertwig & Ortmann, 2001). In order to test whether motivation is a factor in participant attention and comprehension of the sentence contexts, I required a task in which motivational variables such as monetary incentive, feedback and supervision could be manipulated. Eyetracking tasks like those used in Experiments 1 and 2 are not flexible for supervisory manipulation or feedback, so I opted to use the naming paradigm instead.

Although many naming experiments have provided evidence to support Selective Access (Martin et al., 1999; Vu et al., 1998, 2000, 2003), the fact that many studies have provided evidence supporting Reordered Access made it possible that a replication of a naming study could result in a result resembling Reordered Access. However, no matter whether the replication supported Selective or Reordered Access, I could investigate effects of motivation on comprehension of sentence context by biasing participants to pay more or less attention to the sentence context.

I attempted to replicate the findings of a previous naming experiment (Vu et al., 2000) to determine a baseline value for motivational manipulation (Experiment 3). I considered two outcomes for Experiment 3, each of which would inform us of how the factor of motivation would be manipulated in Experiment 4.

If Experiment 3 replicated previous naming experiments by providing data that supported Selective Access, Experiment 4 would be designed to discourage participants to pay attention to the sentence contexts, in order to create a situation in which Reordered Access is more plausible. Task modifications, such as changing the self-paced reading of

the context to a surface-level physical characteristic detection task of the words in the sentence would limit comprehension of the sentences. Participants could also be rewarded for quick responses and would not be given feedback or supervision.

On the other hand, if Experiment 3 did not replicate previous naming experiments, and instead provided a pattern of data consistent with Reordered Access, Experiment 4 would be designed to motivate participants to pay attention to and fully comprehend the sentence contexts. Participants could also be rewarded for accurate responses and given continuous feedback and supervision.

#### 4.1 Experiment 3: Naming Baseline

In Experiment 3, I used strongly subordinate-biasing contexts, adapted from the stimuli of Vu et al. (2000)<sup>6</sup> to provide a baseline activation level of subordinate and dominant meanings. The participants read subordinate-biasing paragraphs ending in a homograph, word by word, at their own pace. Two hundred fifty milliseconds after the presentation of the homograph, the participants were asked to quickly name a probe word that was related to either the subordinate or dominant meaning of the homograph, or unrelated to the homograph. *Selective Access* would predict facilitation of only context-appropriate subordinate meaning probes compared to unrelated control probes because the strong subordinate-biased context can outweigh the effects of frequency. *Reordered Access* would predict facilitation of both context-appropriate and context-inappropriate meaning probes because each meaning is activated due to either the subordinate context (subordinate meaning) or its frequency (dominant meaning).

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<sup>6</sup> Vu et al. (2000) was chosen as the model for this experiment because the full set of stimuli were published in the article. Correspondence with Hoang Vu indicated that earlier stimuli from Martin et al. (1999) could not be easily located.

Previous results of Vu et al. (2000) found a pattern of activation consistent with Selective Access. However, there remained a possibility that this replication could instead result in a pattern of activation that supported Reordered Access. No matter the outcome, it would be possible to investigate effects of motivation by either increasing or decreasing attention and comprehension of the sentential context.

#### *4.1.1 Methods*

##### *Participants*

Forty-nine monolingual English speakers received partial course credit for completing the experiment. All participants had normal to corrected vision and no reading or speaking disabilities.

##### *Materials*

Ninety-six context paragraphs biasing the subordinate meaning of homophones were identical to a subset of those of Vu et al. (1998, 2000). We excluded Vu et al.'s dominant-biased set of paragraphs because the critical comparison between the Reordered and Selective Access theories relies exclusively on meaning activation during the subordinate-biasing context. The context paragraphs consisted of two sentences: a context sentence that strongly biased the subordinate meaning of the homograph, followed by an ambiguous sentence that ended with the homograph itself (see Table 3). As described in Vu et al., no words in the context were lexical associates of the ambiguous word. Probe words, identical to those in Vu et al., were lexical associates that represented the dominant and subordinate meanings of the homograph, and originated from the norms of Nelson, McEvoy, Walling, and Wheeler (1980) and Twilley, Dixon, Taylor, and Clark (1994). Each paragraph was paired with two related probe words

(dominant or subordinate) and two unrelated probe words. Unrelated probe words were created by randomly repairing related probe words from other paragraphs, making sure that no probe was repeated within participants, as shown in Table 3. Subordinate-related probes were paired with subordinate-unrelated probes, and dominant-related probes were paired with dominant-unrelated probes, but did not cross dominance types.

Table 3  
*Experiment 3 example stimuli, with related and unrelated pairings*

Subordinate Biased Paragraphs	Dominance Type	Relatedness Type	
		Related	Unrelated
Ex. 1 The sergeant left the jeep. He approached the base.	Subordinate (appropriate)	STATION	TREE
	Dominant (inappropriate)	SAFE	GROWL
Ex. 2 The botanist looked for a fungus. She investigated the bark.	Subordinate (appropriate)	TREE	STATION
	Dominant (inappropriate)	GROWL	SAFE

The 96 paragraphs were counterbalanced across the 4 probe type conditions (subordinate-related, subordinate-unrelated, dominant-related, and dominant-unrelated) to create 4 lists. Each participant was randomly assigned to one of the four lists. Wh-comprehension questions were presented on 50% of the trials.

In addition, 10 practice sentence trials were adapted from the stimuli of Martin et al. (1999). Critical trials were presented in random order.

#### *Procedure and Equipment*

The sentences and probe words were presented using E-Prime. An E-Prime compatible SR-BOX recorded naming latencies with a microphone. The participants read the following instructions:

*At the beginning of a trial, you will see a fixation cross followed by a series of dashes which represent parts of the scenario to be read. To read each part, press the SPACEBAR on the keypad. At the end of the sentence you will see a word in all capital letters. Please say this word out loud into the microphone as quickly as possible. After some sentences you will see a comprehension question. Type the answer in the box below the question.*

The presentation of the words in the sentence was self-paced, which is a modification from Vu et al. (2000), who utilized fixed-rate presentation, with individualized rates of presentation for each participant. This change was made to allow a more natural reading method, rather than controlled fixed-rate reading. The sentences were presented word-by-word, and the probe word appeared 250 ms after the presentation of the homograph at 6 spaces to the right of the homograph, at which time the homograph disappeared. The probe word disappeared simultaneous with activation of the voice key. On 50% of the trials, a Wh-comprehension question appeared, and the participants were asked to type in the correct answer. At the end of every trial, participants were asked to self-monitor whether their initial vocal response triggered the microphone, and whether the word was pronounced correctly. The participants completed the experiment without an experimenter in the running room.

#### *4.1.2 Results*

Participants answered the comprehension questions correctly 84.9% of the time, (50% of the trials had comprehension questions). Trials in which the incorrect answer was given, the voice key was triggered by a nonvocal sound or incorrect word (3.4%), or the naming latencies were greater than 2.5 standard deviations from the participant's mean (3.7%) were excluded from the analyses. In all, 12.8% of the data were excluded. This figure is less than the sum of the previous values because the values were not

exclusive of each other. The comprehension and error rate are comparable to Vu et al. (2000) who found 4.7% errors and 80.2% correct comprehension responses.

The naming latency means in milliseconds for each probe type, with standard errors in parentheses were as follows: subordinate-related: 505(3), subordinate-unrelated: 511(4), dominant-related: 512(3), and dominant-unrelated: 518(4).

In order to test whether related probes had faster naming latencies than unrelated probes, a mixed model contrasting relatedness (related or unrelated) and dominance (subordinate or dominant) as fixed factors and participants and items as random factors was performed. The mixed model revealed a main effect of relatedness ( $F(1,3974) = 10.22, p < .001$ ), which indicated that related probes were facilitated compared to unrelated probes. There was an effect of dominance ( $F(1,3970) = 6.19, p < .05$ ), which indicated differences in the pools of words selected for each dominance condition. There was no interaction ( $F < 1$ ), indicating an absence of dominance effects on homograph meaning facilitation.

Paired comparisons indicated a relatedness effect within subordinate probes ( $F(1,3975) = 6.11, p < .05$ ) and also for dominant probes ( $F(1,3972) = 4.19, p < .05$ ). This pattern of results confirmed that both of the related probes were facilitated compared to the unrelated control words.

The absence of a dominance x relatedness interaction, together with the facilitation for dominant meaning probes, provide evidence that is inconsistent with the Selective Access view of lexical ambiguity resolution, which predicts that only context-appropriate subordinate meanings should be facilitated during strongly subordinate-biased contexts.

#### *4.1.3 Discussion*

Experiment 3 demonstrated that naming times of both contextually-appropriate and contextually-inappropriate meanings of a homograph are facilitated, compared to unrelated frequency-matched control words when following a strongly subordinate-biased context. These findings are inconsistent with the Selective Access view of lexical ambiguity resolution, which predicts only the context-appropriate meanings should be facilitated in strongly biasing contexts. This finding, however, is consistent with the Reordered Access theory of lexical ambiguity resolution, which predicts that both meanings of the homograph remain active when preceded by a subordinate-biased context. The subordinate meaning should be activated faster due to prior context, and the dominant meaning should be facilitated compared to unrelated controls because of strong activation due to its inherent frequency.

These results do not replicate the majority of previous findings from naming studies, which find that only context-appropriate meanings are facilitated in strong contexts (Kellas et al., 1995; Kellas & Vu, 1999; Martin et al., 1999; Simpson, 1981; Vu et al., 1998, 2000, 2003; Vu & Kellas, 1999). More puzzling is that these results do not replicate Vu et al. (2000), from which the materials originated.

A possible reason for why the outcome of these studies differs from Vu et al. (2000) and previous naming studies is the self-paced nature of the presentation of the stimuli. Previous studies utilized an individualized, but fixed, presentation rate, such that participants could choose a slower or faster rate of word presentation, but this presentation rate remained the same throughout the experiment for each participant, despite individual differences in reading rates. The current study utilized a self-paced

reading procedure, in which every word had a variable rate, depending only on the participant's discretion. A self-paced reading procedure allows the participant to fixate on a word as long as necessary until ready to read the next word, while a fixed presentation rate advances to the next word even if the previous word was not fully processed. Although the self-paced reading rate varied for the participants in the current study, the viewing time for the homograph was fixed at 250 ms. Vu et al.'s presentation time of the homograph was identical to the words in the sentence context (266 ms), but in the current study, it was most often the case that the average reading time of the sentence context (480 ms) was slower than the presentation time of the homograph itself (250 ms). This difference in homograph reading time may have contributed to the pattern of homograph meaning activation in this study.

Another possibility for the differences in homograph meaning activation may be differing participant populations. It is possible that the participants in this study were somehow less-skilled readers than those in Vu et al. (2000). Skilled readers, because they have been found to suppress inappropriate meanings of a homophone faster than less-skilled readers (Lewellen, Goldinger, Pisoni, & Greene, 1993), may produce a pattern of meaning activation akin to Selective Access. Less-skilled readers, because of their difficulty in suppressing the inappropriate dominant meaning, may exhibit a pattern more akin to Reordered Access.

In any case, the current version of the naming study demonstrates activation of the dominant meaning of the homograph even when placed in a strongly subordinate-biasing context. This result is consistent with the Reordered Access theory of lexical ambiguity resolution. The validity of this conclusion is examined in Experiment 4.

#### 4.2 Experiment 4: Motivational Effects on Naming Times

Although the results from Experiment 3 showed that dominant meanings remain active even during a strongly subordinate biasing context, the conclusion that the Reordered Access theory is supported is valid only if the participants had fully attended and understood the sentence contexts. Although the sentence contexts themselves were strongly biasing, they may not have been effective in biasing the subordinate meaning if the participant only partially processed the sentence context.

In Experiment 4, I address this issue by manipulating participant motivation in a naming task. I attempt to increase the participant attention and comprehension of the sentence contexts by modifying the experiment to include variables of monetary incentive, feedback and supervision. The participants' task is identical to that of Experiment 3, except the participants do not self-monitor their responses, they receive monetary rewards for accurate comprehension and quick naming latencies, and feedback about accuracy and latency are assessed on every trial by an experimenter who is in the testing room at all times.

A payoff scheme was created to bias the participant to modify their performance either by attending more to the sentence context, or attending more to quick naming latencies. If the motivational modifications to the experiment are found to increase effort and performance, we may expect to see an increase in attention to the sentence contexts. This may in turn enhance suppression of dominant meaning activation.

### 4.2.1 Methods

#### *Participants*

Sixty-four monolingual English speakers received a minimum of \$10 for completing the experiment, which lasted less than one hour. Each participant had the opportunity to earn an extra \$5 in bonuses for superior task performance (payoff scheme details below). All participants had normal to corrected vision and no reading or speaking disabilities.

#### *Materials*

All stimulus materials were identical to those in Experiment 3, except that practice trials were increased to 20, and 48 additional comprehension questions were generated, such that a comprehension question was asked on every trial.

#### *Procedure and Equipment*

The self-paced reading and naming procedure and equipment were identical to those in Experiment 3, except the following: 1) the participants were informed of a payoff scheme, in which they would receive monetary rewards for superior task performance, 2) participants performed the task in the presence of an experimenter, who evaluated the accuracy of the naming and comprehension responses, 3) comprehension questions were asked on every trial, and 4) feedback about probe word naming latency and comprehension question accuracy was given on every trial.

Two payoff conditions were created. In each payoff condition, both comprehension accuracy and naming latency were evaluated, however the monetary payoff differed between the two payoff conditions. Participants were assigned randomly to one of the two payoff conditions and one of four stimulus lists.

*Latency-Bias payoff condition.* In the Latency-Bias payoff condition, naming latency was weighted more than comprehension. Correct comprehension responses were awarded 50 points, and incorrect responses were not rewarded (0 points). Naming latencies faster than 650 ms were evaluated on a sliding scale, based on the following equation:

$$(650 - \text{latency})/6$$

The reward was capped at 50 points for fast latencies, and responses slower than 650 ms were penalized by 100 points. This equation allowed for the participants to earn positive points for fast responses, such that a 500 ms response, the approximate mean latency for naming probe words in Experiment 3, yielded a 25 point reward. All inaccurate naming responses were given negative 100 points.

This scheme was implemented so that comprehension responses had a consequence (maximum 50, minimum 0), but this consequence was not as salient as the naming responses (maximum 50, minimum -100). Thus, Latency is biased over Comprehension.

*Comprehension-Bias payoff condition.* In the Comprehension-Bias payoff condition, comprehension accuracy was weighted more than naming latency. Correct comprehension responses were awarded 50 points, and incorrect responses were given negative 100 points. Naming latencies were evaluated using the same equation, however the minimum points given was 0, so slow responses were not penalized. All inaccurate naming responses were given negative 50 points.

This scheme was implemented so that naming responses had a consequence (maximum 50, minimum 0), but this consequence was not as salient as the

comprehension responses (maximum 50, minimum -100). Thus, Comprehension is biased over Latency.

#### 4.2.2 Results

Participants answered the comprehension questions correctly 88.4% of the time (88.2% in the Comprehension-Biased and 88.5% in the Latency-Biased payoff conditions, no differences ( $F < 1$ )). Trials in which the incorrect answer was given, the initial naming response was due to a nonvocal sound or pronounced incorrectly (4.3%), or the naming latencies were greater than 2.5 standard deviations from the mean for each participant (4.7%) were excluded from the analyses. In all, 16.9% of the data were excluded. This value may be higher than in Experiment 3 because 50% more trials were eligible for comprehension-based exclusion, and the experimenter was better trained to evaluate the naming errors, compared to participant self-monitoring in Experiment 3.

The naming latency means for the two payoff conditions are summarized in Table 4.

Table 4  
*Naming latency means in milliseconds with standard errors in parentheses for the two payoff conditions*

Payoff Condition	Dominance Type	Relatedness Type	
		Related	Unrelated
Latency Bias	Subordinate (appropriate)	475(3)	488(3)
	Dominant (inappropriate)	481(3)	485(3)
Comprehension Bias	Subordinate (appropriate)	470(3)	474(3)
	Dominant (inappropriate)	473(3)	477(3)

### *Payoff Manipulation*

Compared to the mean naming times in Experiment 3 (511 ms), the participants performed more quickly in Experiment 4 (478 ms). The comprehension accuracy was also better in Experiment 4 (88.4%) than in Experiment 3 (84.9%). This improvement in performance may be attributed to the addition of motivational variables. A mixed model treating experiment (Experiment 3 or 4) as a fixed factor and participants and items as random factors confirmed that the participants had faster naming latencies in Experiment 4 ( $F(1,110) = 6.79, p < .05$ ). A mixed model also confirmed that accuracy was improved in Experiment 4 ( $F(1,130) = 6.24, p < .05$ ).

Motivation may have played a factor in improving overall naming latency and comprehension accuracy, however, the payoff manipulation did not affect naming latencies as predicted. In fact, the means for the Latency-Bias payoff condition produced longer mean naming times (482 ms) than the Comprehension-Bias payoff condition (473 ms), which is opposite of what was intended. It seems that the participants in the Comprehension-Bias condition attended more to the naming aspect of the task than participants in the Latency-Bias condition. The payoff manipulation, thus, with its anomalous pattern of results, is not informative. The failure of the payoff manipulation may also play a role in weakening the results of other analyses in this experiment.

### *Naming Times*

Because the payoff manipulation exhibited anomalous results, it will not be included as a factor in further analyses.

In order to evaluate whether the dominant meaning was active in the subordinate-biasing context, a mixed model contrasting relatedness (related or unrelated) and

dominance (subordinate or dominant) as fixed factors and participants and items as random factors was performed. There was an effect of relatedness ( $F(1,4963) = 9.62, p < .01$ ), such that related probes were facilitated compared to unrelated probes. There was no effect of dominance ( $F < 1$ ). There was no interaction of relatedness and dominance ( $F(2,4960) = 1.62, p > .10$ ), indicating no difference between the amount of facilitation between the subordinate probes and the dominant probes.

Paired comparisons of relatedness within subordinate and dominant conditions indicated that the relatedness effect was only significant within the subordinate condition ( $F(1,4960) = 9.54, p < .01$ ), not the dominant condition ( $F(1,4959) = 1.69, p > .10$ ). This pattern of results is consistent with Selective Access, in that only the subordinate meaning was facilitated compared to controls, and the dominant meaning remained as inactive as the controls.

The interaction between relatedness and dominance was not reliable, however methodological problems may provide an explanation. First, the payoff condition manipulation may have weakened the overall effect of context, because naming times were opposite of the predicted pattern. This anomalous pattern may be due to the participants' lack of understanding of how the payoff scheme functioned. No explicit test of payoff scheme understanding was conducted in Experiment 4. If the participants did not understand how their responses were scored, the payoff manipulations may not have been received in the intended manner, adding variance to the data. In addition, it is possible that the lack of an interaction may be a result of low power due to a smaller set of participants. Experiment 4 employed to a lower number of participants per condition, 8, compared to 12 per condition in Experiment 3.

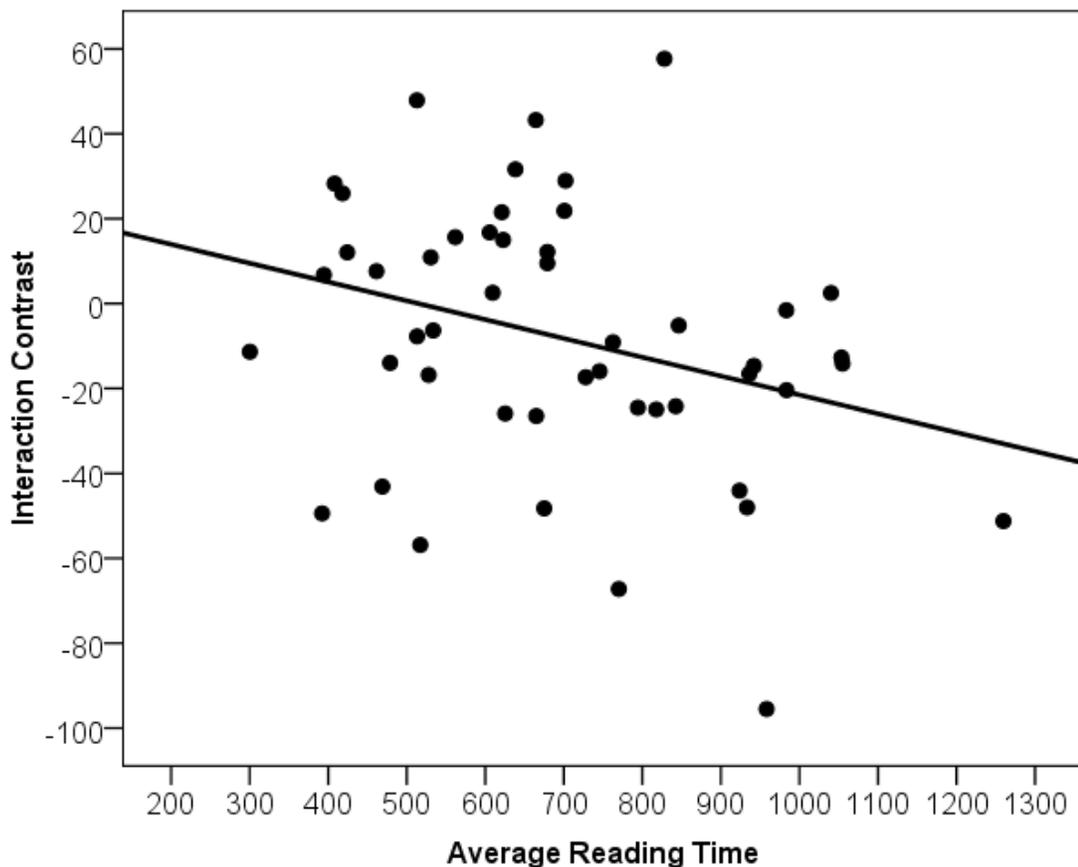
### *Average Reading Times*

In this experiment, participant average reading times per word (over the context sentence and the sentence ending in the homophone) varied widely from 300 ms per word to 1260 ms per word. Average reading rates are about 3-4 words per second, but in self-paced reading, where participants must press a button for each word, it is common to find average reading rates in the 500 – 800 ms range (Ferreira & Henderson, 1990; Holmes, Stowe, & Cupples, 1989; Mitchell & Green, 1978). Differences in reading rates might reflect differences in how carefully a sentence is read and might therefore influence the pattern of activation of the subordinate and dominant meanings in the subordinate biasing contexts. In the current experiment, each participant's average word-by-word self paced reading times may be an indicator of how much attention was paid to the sentence contexts. I correlated the participants' self paced reading times with an interaction term in order to investigate this relationship. The interaction contrast was calculated by subtracting the difference in facilitation for the subordinate and dominant probe types, in the following format: (subordinate related – subordinate unrelated) – (dominant related – dominant unrelated). More negative interaction terms indicated larger subordinate meaning facilitation compared to dominant meaning facilitation.

As shown in Figure 7, average self-paced reading time inversely varied with the interaction contrast: as reading times increased, the interaction term decreased ( $r(49) = -.31, p < .05$ ) ( $F_1(1,47) = 4.90, p < .05$ ). Longer reading times were correlated with more negative interaction contrast terms, indicating that slower readers had greater subordinate meaning facilitation than faster readers. The interpretation of this finding points to slower readers paying more attention to the sentence context, activating the appropriate

subordinate meaning exclusively. This is in contrast to quicker readers, who may have activated the inappropriate dominant meanings. Slower readers did not, however, have slower naming latencies, indicating that naming latencies of slower readers do not simply reflect later time points in ambiguity resolution ( $r(62) = .14, p > .10, F_1(1,62) = 1.26, p > .10$ ).

Figure 7. Experiment 4 regression of average self paced reading time with relatedness x dominance interaction contrast including both payoff conditions. More negative interaction terms were observed for longer reading times.



The notion that slower readers activate the appropriate meaning exclusively is counterintuitive with respect to previous findings that less-skilled readers have difficulties suppressing inappropriate meanings (Lewellen et al., 1993). However, the slower readers in this experiment may not necessarily have been *less-skilled* readers,

instead they may have been particularly cognizant of the requirements of the task. In fact, slow reading of the sentence context was not penalized in this version of the naming paradigm. However, correct comprehension was rewarded and incorrect comprehension was penalized (sometimes heavily). Astute participants may have figured out that reading the sentence very slowly gave them a better chance of understanding the sentence. This may have led them to process the sentence context to the fullest, such that when they were to name the probe word, the biasing sentence context was optimally utilized.

#### *4.2.3 Discussion*

In Experiment 4, the addition of motivational factors such as monetary incentive, feedback and supervision affected the performance of the participants, such that naming latencies and comprehension accuracy were improved, compared to Experiment 3. Motivation may have increased attention to the subordinate-biased context, however, its effects on subordinate meaning facilitation were not reliable, as there was no interaction between relatedness and dominance. There was, however, a significant relatedness effect within subordinate probes which was not evident for dominant probes. The lack of interaction is a problem for Selective Access, however, the relatedness effect that was exclusive to the appropriate homograph meaning, is entirely consistent with Selective Access.

Because the reading times for the subordinate biasing context varied widely in this experiment, it was possible to evaluate the effects of average self-paced reading times on the advantage of appropriate vs. inappropriate probe naming times. The correlation between average reading time and the advantage of subordinate meanings over dominant meanings indicated that slower readers were more likely to selectively

activate the appropriate meaning of the homophone. This finding is promising for the Selective Access theory of lexical ambiguity resolution.

The findings of Experiment 4 have shown that motivation does play a role in improving participant performance, increasing naming speed and comprehension accuracy. However, its effects on attention to sentence context are not straightforward, as the lack of an interaction between dominance and probe relatedness points to Reordered Access, and the exclusive facilitation of subordinate probes and the relationship between reading times and selective access of the subordinate meaning point to Selective Access.

In order to make a clear conclusion about how motivation can affect the attention to the subordinate biasing context, and thus indirectly influencing the activation of homophone meanings, further experimentation is required. It may be necessary to create different payoff schemes that make comprehension of the sentence context highly salient. In the current experiment, participants may not have emphasized attention to the sentence context over the quickness of naming, simply because the payoff manipulation was not well understood. Participants may be better aware of the payoff scheme if practice trials demonstrating the differences in pay scale were more salient. These changes may make the influence of motivation on task performance more transparent.

## CHAPTER 5

### BILINGUAL LANGUAGE ACTIVATION IN THE VISUAL WORLD

This set of experiments focuses on multiple meaning access between languages. Bilingual word recognition requires the selection from even more cohort competitors than monolinguals, because bilingual spoken input temporarily matches words from more than one language. Bilinguals have the task of not only selecting from a set of words that match the spoken signals in the language it was spoken, but also words that match the auditory signals from the inappropriate language.

The current predominant view on multiple language activation is that languages are nonselectively accessed, such that while processing words in a target language, nontarget words are also activated (Dijkstra, 2005). This is in contrast to the earlier view that languages are selectively accessed (Gerard & Scarborough, 1989; Scarborough, Gerard, & Cortese, 1984). Extensive research has utilized single word experiments to study multiple language activation (De Moor, 1998; Dijkstra et al., 1999, 2000; Gerard & Scarborough, 1989; Grainger & Dijkstra, 1992; Scarborough et al., 1984; Van Heuven et al., 1998), providing evidence mainly in favor of language-nonselective access. More recently, researchers have been interested in the effects of sentential context and language context on the activation of multiple languages when words are not isolated (Duyck et al., 2007; Marian et al., 2003; Marian & Spivey, 2003; Schwartz & Kroll, 2006; Spivey & Marian, 1999; Van Hell & De Groot, in press). Reading studies have found that sentence

contexts effects cannot eliminate activation of the nontarget language in low constraining contexts (Duyck et al., 2007, Schwartz & Kroll, 2006; Van Hell & De Groot, in press). Some researchers have also claimed that when sentence contexts are highly constraining, selective access of the target language can occur (Schwartz & Kroll, 2006; Van Hell & De Groot, 2008). However, their results are confounded with the possibility that intralexical priming, instead of top-down sentential context, contributed to the reported effects. In order to ensure that top-down contexts semantically constrain multiple language activation, it is necessary to exclude lexical primes from the contextual stimuli.

The visual world paradigm can provide evidence for the time course of contextual influence on multiple language activation in bilingual word recognition. Recent within-language studies have established the time course of lexical processes using the visual world paradigm (Allopenna et al., 1998; Dahan et al., 2001; Tanenhaus et al., 1995), and time course of within-language context effects have also been clarified (Experiment 2, above; Huettig & Altmann, 2007). Previous studies have demonstrated that a monolingual language context is not sufficient to eliminate nonselective access in spoken language processing in the visual world paradigm (Marian et al. 2003; Marian & Spivey, 2003; Spivey & Marian, 1999). However, the influence of meaningful linguistic context on multiple language activation has not been investigated in the spoken domain. In the current experiments, I investigate whether linguistic context can modulate nonselective access of multiple languages using in the visual world eyetracking paradigm. I also extend the results of previous spoken language findings by measuring the activation of the nontarget language over time.

The BIMOLA and BIA+ models of word recognition are contrasted in the current experiments. Both the BIMOLA and BIA+ assert that bottom-up processing of multiple languages is *nonselective*, such that phonological and orthographic features are processed by both languages simultaneously. The two models, however, diverge in the language selectivity of the context on lexical processing. BIA+ assumes that sentence context is *language-nonselective*, such that both the nontarget and the target language are influenced by the semantic context. BIMOLA assumes that global language information affects each language network separately, so semantic context effects are *language-selective*.

Experiment 5 provides a baseline activation of multiple meaning access with Spanish/English bilingual participants using neutral imperative context, e.g., *Look at the moon*. Experiments 6 (English) and 7 (Spanish) manipulate linguistic sentence context to be either neutral or conceptually biasing towards the meaning of the word in the target language. An example of conceptually biasing context in Experiment 6 is the following: *Jimmy has always been curious about the vastness of our galaxy, and was most interested in the moon*. At target onset, four pictures appeared: the English Target (*moon* “luna”), the Spanish Phonological Competitor (*doll* “muñeca”) and two fillers unrelated in phonology in both languages (*pillow* “almohada”, *rock* “piedra”). The Spanish Phonological Competitor overlapped in word-initial phonemes. None of the Spanish competitors overlapped in semantics or visual similarity with the English Targets, so any activation of the Spanish Competitor from the spoken input indicated activation of the nontarget Spanish language. In Experiment 7, similar materials were generated in the

Spanish language, with English phonological competitors used to index subliminal activation of the nontarget English language.

### 5.1 Experiment 5: Bilingual Activation in the Visual World

Experiment 5 established a baseline level of nontarget language activation for Spanish/English bilingual participants in a visual world paradigm similar to Marian & Spivey (2003). This experiment differs from Marian & Spivey in three ways: 1) I measured the activation of the nontarget language in real time. I was concerned that reporting data over an entire trial, instead of sampling in 100 ms intervals from target onset, would measure strategic post-lexical processing, rather than automatic language activation. 2) I presented the participants with the target objects only at the onset of the target word, in order to preclude visual preview effects and repetition effect. I was concerned that the active naming of the objects and the repeat presentation 4 times would cause participants to create strategic looking patterns to the competitor and filler objects. 3) Most obviously, I recruited a different population of bilingual speakers. This change is beneficial in generalizing nontarget language effects to multiple language combinations.

#### *5.1.1 Methods*

##### *Participants*

Ten Spanish-English bilinguals (3 male, 7 female, average 21.7 years old) who became fluent in both Spanish and English before age 8 were paid for participation. Participants who learned Spanish in Spain were excluded from this and the next two studies because of the large difference in pronunciation. All participants had normal or corrected vision. Participants completed a language background questionnaire which

assessed bilingual language background (Marian, Blumenfeld, & Kaushanskaya, 2007). Participant profiles are presented in Appendix D.

### *Materials*

Fourteen target words were chosen such that Spanish phonological competitors matched English targets in initial phonological overlap according to aspiration, place and manner of articulation. For example, the English Target *moon* /mun/ shares the same initial phonemes as the Spanish Phonological Competitor *muñeca* /munjeka/, which means “doll.” The average word frequencies between the competitors and targets were controlled. All words were concrete, imageable nouns. The auditory stimuli were imperatives that followed the structure *Look at the moon* and were recorded by a native English speaker.

At target onset, four pictures appeared on the screen: two critical pictures: the actual English Target and the Spanish Phonological Competitor, and two unrelated Filler Objects. Filler Objects had names that did not begin with the same phonemes as the English Target or Spanish Competitor, and were not semantically or visually related to the critical pictures. Norms to ensure that the pictures represented the intended targets are presented below.

Similar to Experiment 2, the visual stimuli consisted of four pictures arranged in a 3x3 grid on a white background with a fixation cross in the center for each critical trial. The critical pictures appeared in the upper left, upper right, lower left, or lower right corner, arranged so that the Target and Competitor objects appeared in each corner an equal number of times for every participant. The two remaining corners contained Filler

Objects. In addition to the 14 critical target trials, 38 filler trials with targets and fillers unrelated in phonology were constructed.

### *Norming*

*Picture agreement norms.* Picture agreement norms confirmed that there was high agreement in names for the pictures chosen to represent the English Targets and Spanish Phonological Competitors. Twenty monolingual English speakers completed an English picture naming task, and twenty native Spanish speakers completed an identical picture naming task in Spanish. Only one picture appeared on each screen, simultaneously with a box in which they were asked to type the name of the picture of the object represented. Trials were coded as having correct agreement when the response included the target in any part of the answer, including misspelled words and plurality differences, but not including synonyms or other names. The agreement between the participants' responses and the intended labels was 97.9%. The agreement between the participants' responses and the intended Spanish labels was 87.9%. The lower agreement score in Spanish may have been due to regional differences in preferences of word choice for a particular object. Both English and Spanish scores, however, indicated high name agreement.

*Phonological overlap in Spanish.* In choosing the pictures to represent the Phonological Competitors, it would present a confound if a Spanish Phonological Competitor picture was likely to be labeled with a name beginning with the same phonemes as the English target in that particular trial. Data from the Spanish naming task above were analyzed for phonological overlap, and no responses for the Spanish Competitor pictures indicated any phonologically similarity to the English target.

*Picture saliency norms.* Picture saliency norms were conducted to evaluate any difference in saliency among the critical pictures. Ten participants were asked to view pictures silently on the computer screen while a head-mounted eye-tracker monitored their eye movements. The 14 critical trials, along with 38 filler trials were presented in a random order. On each trial, four pictures appeared on the screen for 5 seconds, and a drift correction procedure was conducted between every trial. The sets of four pictures were the same as in Experiment 5.

The dwell time percentages for each object type were the following: Target: 20.5%, Competitor: 20.6%, Filler Objects: 19.2%. A mixed model treating object type (Competitor vs. Filler) as a fixed factor and items as a random factor found no advantage of Competitors compared to Fillers ( $F < 1$ ) Thus, there were no advantages in saliency for pictures representing the competitors over pictures representing the fillers.

#### *Procedure and Equipment*

Experiment 5 employed an Eyelink II head-mounted binocular eye tracking device. The eye cameras were mounted on a headgear, with a sampling rate of 500 Hz. The auditory sentences and their corresponding slides were presented in a random order. Participants read these instructions:

*In this experiment, you will hear a sentence. At the end of the sentence, you will see four objects on the screen. Your task is to click on the object that matches the word mentioned in the sentence you just heard and drag it to the center of the screen. For example, if you heard "Look at the table", you would click on the TABLE and drag it to the center of the screen.*

The data were collected using SR Research Experiment Builder and Data viewer software.

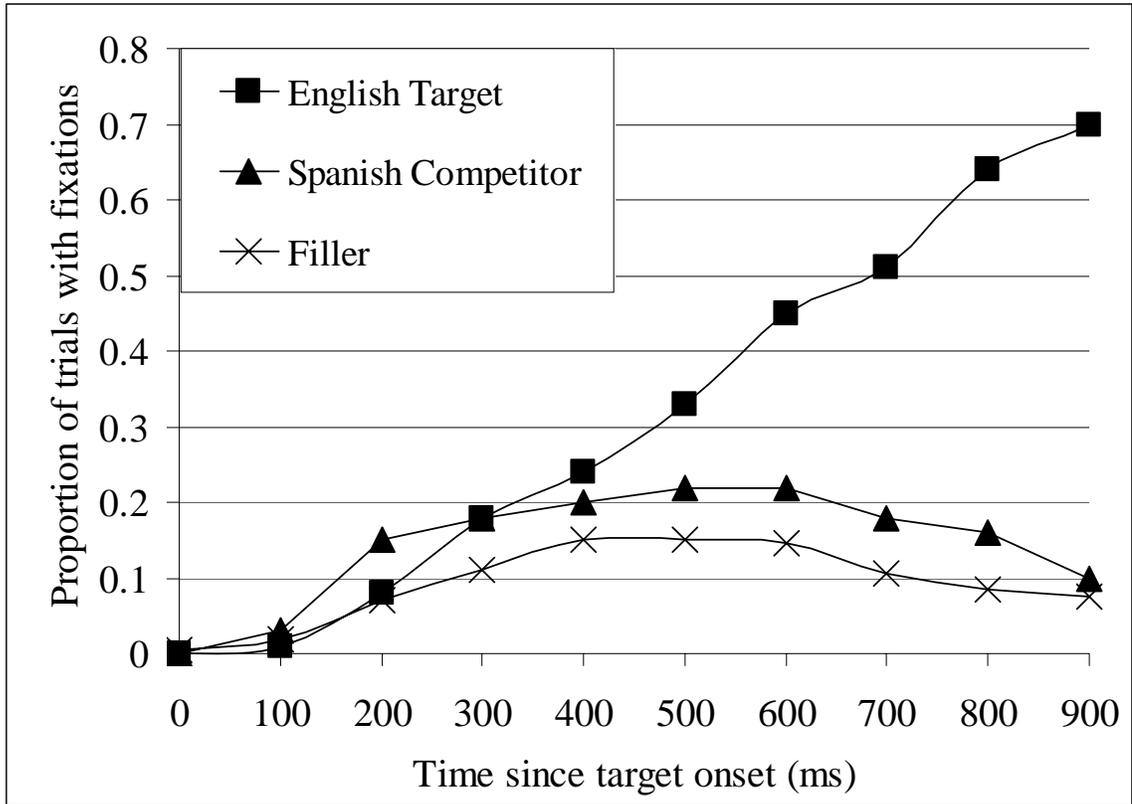
### 5.1.2 Results

There were two critical pictures on each trial, the English Target and the Spanish Competitor. The two eye movement measures analyzed included the following:

1. First run dwell time on each of the critical pictures
2. Visual bias towards Spanish competitors, measured by log gaze probability ratios to Spanish competitor and filler pictures from target word onset until 1000 ms after onset

Figure 8 presents the proportion of looks to all four critical pictures during each 100 ms interval after target onset. The English Target seems to attract fixations starting at the 300 ms interval, and the Spanish competitor seems to attract more looks than fillers starting at around 200 ms and continuing until 800 ms.

Figure 8. Experiment 5 proportion of trials within a 100 ms interval with fixations on the English Target, the Spanish Competitor, or the average of the filler objects. The first time interval is 0 – 99 ms after target word onset.



*First run dwell time*

First run dwell time was analyzed in order to evaluate initial processing time for each of the fixated objects. The average first run dwell times in milliseconds, with standard errors in parentheses were the following: English Target: 630(29), Spanish Competitor: 259(17), and Filler Objects: 216(10). In order to determine whether the nontarget language was activated at above chance levels, first run dwell times to the Spanish Competitors were compared to average first run dwell times to the unrelated Filler Objects. Because Filler Objects should not attract fixations when the English Target is spoken, and only be fixated by chance, any bias towards Spanish Competitors over Filler Objects would indicate preferential processing of the nontarget language.

A mixed model analysis treating object type (Spanish Competitor or Filler) as a fixed factor and participants and items as random factors found that Spanish Competitors had longer first run dwell times than Filler Objects, as expected ( $F(1,214) = 6.24, p < .05$ ). This result suggests that the nontarget language, represented by the Spanish Competitor, was activated at levels higher than chance. This finding is consistent with and extends the previous studies using the visual world paradigm (Marian et al. 2003; Marian & Spivey, 2003; Spivey & Marian, 1999) by indicating that nontarget language activation is apparent during initial processing of the spoken target.

#### *Visual bias to Spanish Competitors*

In order to evaluate the time course of nontarget language activation, I compared the observed proportion of looks to the proportion that would be expected on the basis of chance alone. As per Arai et al. (2007), log gaze proportions were used in order to circumnavigate problems of interdependence between looks to pictures. The same formula for log ratios of Arai et al. was used to evaluate the strength of visual bias towards Spanish Competitors:

$$\ln(P(\text{Spanish Competitor})/P(\text{Filler Objects}))$$

$P(\text{Spanish Competitor})$  is the likelihood of fixating the Spanish Competitor object during the 100 ms interval, and  $P(\text{Filler Objects})$  is the likelihood of fixating a filler object during the 100 ms interval. Using the log of the ratio of likelihoods yields a number that is either 0, positive (indicating a Spanish Competitor Visual Bias) or negative (indicating a Filler Object Visual Bias). Note that there are missing values for several log-ratio values due to zero values at the early bins: no ratio can be determined using zero as a denominator, nor a log value for zero. Due to missing values, statistics could only be

computed starting at the 200 ms interval, and even so, missing values strongly impacted the degrees of freedom for either participants or items at most of the intervals.

If Spanish Competitors are activated more than unrelated Filler Objects (positive log values), this would be evidence for higher activation than expected by chance. Mixed models treating log ratio (log ratio vs. 0) as a fixed factor, and participants or items as random factors for each 100 ms interval from 200 ms until 1000 ms after target onset, are shown in Table 5. There was a visual bias towards Spanish Competitors compared to Filler objects starting at 200 ms, significant by participants and marginally by items. This effect continued again at 800 and 900 ms.

Table 5

*Experiment 5 log ratios of visual bias towards Spanish competitors over fillers to zero, including mixed model effects in 100 ms time intervals from target onset*

Bin	Log-ratio	Log-ratio Main Effects			
		dfs	F <sub>1</sub>	dfs	F <sub>2</sub>
200	0.69	1,6	60.16***	1,2	16.00 <sup>m</sup>
300	0.41	1,7	1.54	1,4	3.15
400	0.22	1,16	1.09	1,7	2.38
500	0.27		<1	1,10	1.77
600	0.33	1,18	2.77	1,9	4.58 <sup>m</sup>
700	0.44	1,9	2.13	1,18	1.88
800	0.60	1,7	7.56*	1,7	4.28 <sup>m</sup>
900	0.60	1,6	11.94*	1,5	11.05*

<sup>m</sup>*p* < .10, \**p* < .05, \*\**p* < .01, \*\*\**p* < .001

### 5.1.3 Discussion

The nontarget language, Spanish, was activated at higher than chance levels in a monolingual English context in Experiment 5, as evidenced by first run dwell times, an

indicator of initial processing of the stimuli. Time course effects were less reliable, but indicated that Spanish Competitors had longer first run dwell times than expected by chance as early as 200 ms. The activation of the nontarget language when instructed only in a monolingual language context is consistent with previous visual world studies (Marian et al. 2003; Marian & Spivey, 2003; Spivey & Marian, 1999). Furthermore, in contrast to previous studies that compared fixations over an entire trial, I was able to show that initial processing of the spoken stimuli supports nonselective language access.

## 5.2 Experiment 6: Context Effects on Bilingual Language Activation

Experiment 5 demonstrated that the nontarget language is activated early in processing during a monolingual target language context for Spanish-English bilinguals. However, a monolingual language context may not be strong enough to constrain nontarget language activation. A stronger, conceptually biasing linguistic context may modulate multiple language access, in a similar way that semantic context effects have been found to influence monolingual lexical access (Duffy et al., 1989; Simpson et al., 1989; Stanovich & West, 1979, 1981, 1983; West & Stanovich, 1982).

Duyck et al. (2007) demonstrated that for Dutch-English bilinguals, low-constraining sentence contexts do not nullify the activation of the nontarget language, as shown by facilitation of cognates in lexical decision during reading paradigm. Unfortunately, the lexical decision paradigm, as noted in Chapter 2, is complicated by the suggestion that it measures post-lexical decision processes and involves a meta-linguistic task (Balota, 1990; Balota & Chumbley, 1984, 1985; Duschere & Holender, 2005; Lorch et al., 1986; Neely, 1991; Neely & Keefe, 1989; Seidenberg et al., 1984; Stanovich & West, 1983; Theios & Muise, 1977; West & Stanovich 1982). In contrast, the visual

world paradigm has been shown to measure the earliest moments of lexical processing (Alloppenna et al., 1998; Dahan et al., 2001; Tanenhaus et al., 1995) and the time course of within-language context effects (Experiment 2, above; Huettig & Altmann, 2007). Thus, the visual world paradigm may better measure the effects of context on nontarget language activation by providing a clearer time course of meaning activation.

The low-constraint sentence contexts in Duyck et al. (2007) may also have contributed to the absence of context effects on nontarget language activation. A more biasing, semantic-level sentence context may be more effective in modulating nonselective language activation. This prediction is in line with the Bilingual Interactive Activation+ (BIA+) model of bilingual word recognition (Dijkstra & Van Heuven, 2002). The model assumes that multiple lexicons are integrated, so bottom-up processing is language-nonselective. This model also incorporates linguistic context, such that top-down semantic context directly affects bilingual word activation by influencing word identification. The BIA+ model further assumes that semantic context effects are language-nonselective, such that context effects do not only influence one, but multiple languages.

BIMOLA is similar to BIA+ in that it also predicts that bottom-up lexical processing is language nonselective. However, it predicts that global language information is language-selective, so semantic context should affect only lexical activation the target language. Thus, the BIA+ and BIMOLA have different predictions about how semantic context in the target language will affect nontarget language activation.

To evaluate linguistic sentence context effects on multiple language activation, Experiment 6 contrasts Neutral-Imperative context with context that is Conceptually-Biasing towards the meaning of the word in the target language. I expect to replicate the nontarget language activation in the Neutral-Imperative context, as found in Experiment 5. If the Conceptually-Biasing context is able to modulate language-nonspecific access, I expect activation of the Spanish Competitor in the Neutral-Imperative context, but not the Conceptually-Biasing context. This result is predicted by the BIA+ because it assumes that linguistic context effects are language-nonspecific: both the target language and the nontarget language should be modulated by semantic context. However, the BIMOLA assumes language-specific context effects, such that only the target language is affected, and the nontarget language remains unaffected.

### *5.2.1 Methods*

#### *Participants*

Twenty-eight Spanish-English bilinguals (average age 22.5, 14 males, 14 females) who became fluent in both Spanish and English before age 8 were paid for participation. All participants had normal or corrected vision. All participants completed a language background questionnaire (participant profiles can be found in Appendix D).

#### *Materials*

The fourteen target words are identical to those in Experiment 5. Two linguistic context conditions were created for each of the fourteen English targets. In the Neutral-Imperative context condition, participants heard the same sentence context as in Experiment 5, in which the sentence did not carry additional conceptual information other than the target word itself (e.g., *Look at the moon*). In the Conceptually-Biasing

context condition, participants heard a sentence context that semantically constrained the target toward the English word's meaning (e.g., *Jimmy has always been curious about the vastness of our galaxy, and was most interested in the moon*). No lexical associates were used in the Conceptually-Biasing sentences, in order to exclude bottom-up lexical priming as a factor in activation of the target. The auditory stimuli were recorded by a native English speaker. At target onset, four pictures appeared on the screen in the same manner as in Experiment 5. In addition to these 14 critical target trials, 38 filler trials with unambiguous targets were constructed.

Two blocking conditions were created such that participants saw 7 critical trials in the Conceptually-Biasing context condition, and 7 in the Neutral-Imperative context condition, in one of two block orders. The trials were blocked such that the participants either saw the Conceptually-Biasing contexts before the Neutral-Imperative contexts, or the Neutral-Imperative contexts before the Conceptually-Biasing contexts. Items were counterbalanced across the two lists such that participants saw each item once.

### *Procedure and Equipment*

The Neutral-Imperative context trials were preceded by the same instructions as in Experiment 5. The Conceptually-Biasing context trials were preceded with the following instructions:

*In this experiment, you will hear a sentence that describes a scenario. At the end of the sentence, you will see four objects on the screen. Your task is to look at the object that matches the last word of the sentence you just heard and drag it to the center of the screen. For example, you might hear "Cindy went to the store to pick up a dress". Four pictures: a dress, a bicycle, a computer, and a pen, will appear on the screen. You will look at the dress and drag it to the center of the screen. You will also have a comprehension question after every sentence. Please say your answer (YES or NO) out loud.*

The data were collected and organized using SR Research Experiment Builder and Data viewer software.

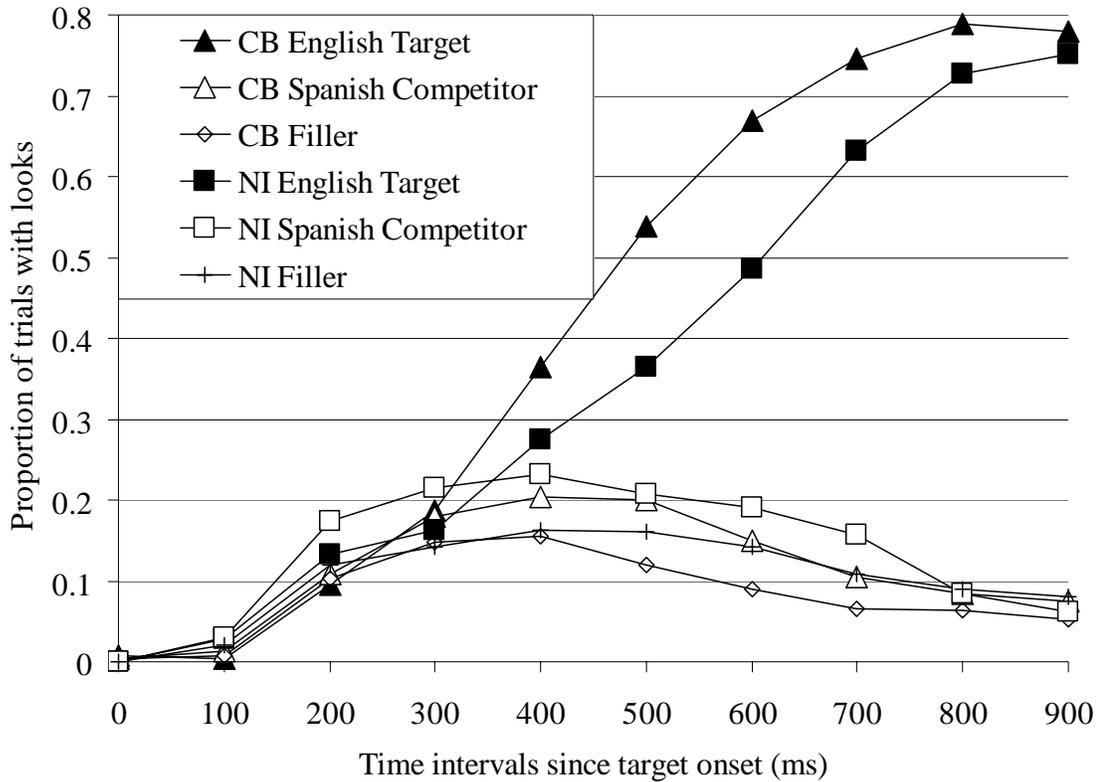
### *5.2.2 Results*

There were two critical pictures on each trial, the English Target and the Spanish Competitor. The three eye movement measures analyzed include the following:

1. First run dwell time on each of the critical pictures
2. Visual bias towards Spanish competitors, measured by log gaze probability ratios to Spanish competitor and filler pictures from target word onset until 1000 ms after target onset
3. Context effects on the English Target and Spanish Competitor

Figure 9 presents the proportion of looks to all four critical pictures during each 100 ms interval after target onset for the two lists. At 200 ms, it appears that participants began to look at the critical pictures, and at 400 ms, it appears that participants began to look at the English Targets more than Filler Objects. The Conceptually-Biasing context seemed to increase looks to the English Target compared to the Neutral-Imperative context from the onset of fixations. The Spanish Competitors seemed to attract more looks than Fillers from 300-700 ms.

Figure 9. Experiment 6 time course of probability of fixations on critical pictures and fillers at each 100 ms interval from target onset, with Conceptually-Biased context (CB) represented with triangles and Neutral-Imperative context (NI) represented with squares. The first interval is 0-99 ms after target onset.



#### *First run dwell time*

First run dwell time was analyzed in order to evaluate initial processing time for each of the fixated objects. The average first run dwell time for critical objects in each context condition in milliseconds, with standard errors in parentheses, were as follows: Neutral-Imperative context: English Target: 670(27), Spanish Competitor: 252(12), Fillers: 230(8). Conceptually-Biasing context: English Target: 666(23), Spanish Competitor: 277(15), Fillers 227(11).

In order to determine whether the nontarget Spanish language was activated at above chance levels, first run dwell times to the Spanish Competitors were compared to average first run dwell times to the unrelated filler objects. A mixed model treating object

type (Spanish Competitor or Filler) and context type (Neutral-Imperative or Conceptually-Biased) as fixed factors and participants and items as random factors found a main effect of object type ( $F(635) = 10.87, p < .01$ ). There was no effect of context condition ( $F < 1$ ) and no interaction between factors ( $F(1,633) = 1.40, p > .10$ ).

These findings suggest that the nontarget language, represented by the Spanish Competitor, were activated at levels higher than chance, and that conceptually constraining context did not reduce the availability of the nontarget language. The maintenance of activation for the nontarget language competitor is consistent with BIMOLA, and is not consistent with BIA+. This finding is similar to previous findings that context does not modulate the nonselectivity of language activation (Duyck et al., 2007), however it extends to phonological pairs that overlap only in initial sounds. Although contexts used in this experiment were more semantically constraining than in previous experiments, multiple languages were still activated.

#### *Visual bias to Spanish Competitors*

In order to evaluate the time course of nontarget language activation in the two context conditions, I compared the observed proportion of looks to the proportion that would be expected on the basis of chance alone. To evaluate this activation, I used log gaze ratios as a measure of visual bias to the Spanish Competitors compared to Filler Objects. If Spanish Competitors attract more looks than chance in either the Neutral-Imperative or Contextually-Biased context, or both, multiple languages have been activated. Mixed models treating log-ratios (log-ratio vs. 0), context condition (Neutral-Imperative or Conceptually-Biasing), and block order (Neutral-Imperative first or

Conceptually-Biasing first) as fixed factors, and items or participants as random factors, are reported in Table 6.

Table 6

*Experiment 6 log ratios of visual bias towards Spanish competitors over fillers for each context condition, including mixed model effects in 100 ms time intervals from target onset.*

Bin	Log-ratios by Context Type		Log-ratio Main Effects			
	Neutral	Conceptually Biasing	dfs	F <sub>1</sub>	dfs	F <sub>2</sub>
200	0.57	-0.03	1,30	7.64*	1,18	18.29***
300	0.52	0.09	1,64	5.90*	1,33	38.57***
400	0.36	0.29	1,66	5.24*	1,38	21.60***
500	0.16	0.72	1,50	16.66***	1,54	19.28***
600	0.33	0.81	1,52	24.30***	1,54	14.44***
700	0.32	0.73	1,46	25.12***	1,40	11.39**
800	-0.08	0.50	1,23	77.57***	1,32	3.22 <sup>m</sup>
900	-0.18	0.00	1,26	34.88***	1,12	<1

<sup>m</sup> $p < .10$ , \* $p < .05$ , \*\* $p < .01$ , \*\*\* $p < .001$

Main effects of the log-ratio were significant by both participants and items from 200 to 700 ms, and significant by participants, marginal by items at 800 ms, and significant by participants only at 900 ms. There were no block effects. This pattern of activation indicated that the nontarget language was activated above chance levels from early time points throughout the trial. The interaction of sentence context on the log-ratio test was only reliable from 500 to 800 ms by participants (500 ms:  $F_1(2,56) = 11.29$ ,  $p < .001$ ,  $F_2 < 1$ ; 600 ms:  $F_1(2,52) = 3.39$ ,  $p < .05$ ,  $F_2(2,54) = 1.57$ ,  $p > .10$ ; 700 ms:  $F_1(2,46)$

= 6.98,  $p < .01$ ,  $F_2 < 1$ ; 800 ms:  $F_1(2,26) = 6.48$ ,  $p < 0.01$ ,  $F_2 < 1$ ).<sup>7</sup> The weak interaction indicated a slight increase in nontarget language activation in later time intervals for conceptually biasing context compared to neutral context.

In order to explore whether there was an interaction between context type and early or late time intervals on competitor activation, mixed models treating context condition (Neutral-Imperative or Conceptually-Biasing), and time interval (early: 200-400 ms or late: 500-700 ms) as fixed factors, and items or participants as random factors, were performed. There was no main effect of context condition ( $F_1(1,135) = 1.19$ ,  $p > .10$ ,  $F_2 < 1$ ) or time interval ( $F_1(1,135) = 2.66$ ,  $p > .10$ ,  $F_2 < 1$ ). There was no interaction of condition and time interval ( $F_1(1,135) = 1.61$ ,  $p > .10$ ,  $F_2 < 1$ ). Thus, the weak interaction between context and log-ratio may not be an indication of real context effects.

#### *Semantic Context Effects on Targets and Competitors*

To evaluate whether the semantic context differentially activated the target language and nontarget language, I compared the proportion of looks to the English target and the Spanish Competitors in different context conditions over time. In order to explore whether context effects differed between languages, a mixed model treating context condition (Neutral-Imperative or Conceptually-Biasing), and language type (English Target or Spanish Competitor) as fixed factors, and items and participants as random factors, was performed for each 100 ms time interval. The interaction of context and language type was significant from the 400 through the 700 ms intervals (400 ms:  $F(1,739) = 14.17$ ,  $p < .001$ ; 500 ms:  $F(1,766) = 7.96$ ,  $p < .01$ ; 600 ms:  $F(1,767) = 11.31$ ,  $p < .01$ ; 700 ms:  $F(1,780) = 6.90$ ,  $p < .01$ ). Paired comparisons revealed that context effects

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<sup>7</sup> Less stringent tests of this interaction, comparing raw values of the Spanish Competitor to Fillers, indicated no significant interactions at any time interval.

only within English Targets from 400-700 ms (400 ms:  $F(1,750) = 8.17, p < .01$ ; 500 ms:  $F(1,766) = 18.76, p < .001$ ; 600 ms:  $F(1,767) = 17.56, p < .001$ ; 700 ms:  $F(1,780) = 8.27, p < .01$ ), and no context effects within Spanish Competitors at any interval ( $F < 1$ ). Thus, context differentially affected the target and nontarget languages, as it boosted activation of the target language, and did not affect the nontarget language. The isolation of context effects to the target language is consistent with BIMOLA. This result is inconsistent with the BIA+ because it assumes language-nonspecific effects of context on lexical activation.

### 5.2.3 Discussion

Evidence for nontarget language activation was evident in both first run dwell times and visual bias measures, such that the Spanish competitors were activated above chance levels starting at 200 ms and continuing throughout the trial. Because eye movements take about 150-200 ms to plan, this is evidence for multiple language activation at the earliest measurable time points. This is one of very few bilingual studies that provides this kind of online time course data. In addition, there was no reliable context effect on the size of the nontarget language activation at any time point. The absence of context effects is consistent with previous reading studies (Duyck et al., 2007) using low-constraint sentence contexts and previous visual world studies using monolingual language contexts (Marian et al., 2003; Marian and Spivey, 2003; Spivey & Marian, 1999). This lack of context effects is surprising, given the literature on monolingual word recognition that gives semantic context a role in lexical access (Duffy et al., 1989; Simpson et al., 1989; Stanovich & West, 1979, 1981, 1983; West & Stanovich, 1982) and in studies of lexical ambiguity resolution, which demonstrate that

semantic context plays a role within 200 ms of homophone offset (Seidenberg et al., 1982; Sereno et al., 2003; Tabossi, 1988; Tabossi & Zardon, 1993; Tanenhaus et al., 1979). The absence of context effects on the nontarget language is also inconsistent with the predictions of the BIA+ model of bilingual word recognition, which assumes that top-down linguistic context like the conceptually biasing context in the current experiment should affect both the target and nontarget languages (Dijkstra & Van Heuven, 2002). A direct comparison of context effects on language type in this experiment showed that there were large effects of context on the target language but no effects on the nontarget language. This lack of context effects on nontarget language activation is, however, consistent with the BIMOLA, which assumes that languages have separate lexicons, but which activate in parallel. Each language can be activated independently based on top-down constraints, in this case, the semantics of the target language.

In comparison to multiple homophone meaning access within languages (Experiments 1 and 2), it appears that multiple meanings both within and between languages are activated at early time intervals. However, in comparing context effects, conceptually-biasing context modulated the activation of the inappropriate meaning of a homophone (Experiment 2), but did not modulate multiple meaning access of word-initial phonological competitors between languages (Experiment 6). I offer two explanations for this difference in contextual efficacy.

First, it is possible that semantic context is language-selective for bilinguals, because of their enhanced ability to inhibit irrelevant information (Bialystok, 2001, 2005; Green, 1998; Kroll & DeGroot, 1997). Bilinguals have been found to excel in tasks requiring attention and control, as compared to monolinguals (Bialystok, 2001). These

enhanced executive functions have been attributed to bilinguals' extensive practice in inhibiting irrelevant language from an early age. Although monolinguals also have practice in language inhibition, bilinguals have the additional daily task of inhibiting an irrelevant language. Having superior cognitive control, especially in the domain of language processing, may allow language-selective processing in bilinguals.

A related question is whether a bilingual's practice with language inhibition extends generally to other inhibitory processes. Would enhanced inhibitory skill between languages also improve within-language meaning inhibition? If so, bilinguals may have enhanced ability to inhibit irrelevant meanings in a homophone paradigm. Alternatively, a bilingual's inhibitory skill may be localized to between-language inhibition. Unfortunately, the current study does not contrast within-language activation for bilinguals. Further experimentation is required to investigate within-language meaning inhibition for bilinguals.

The results of Experiments 2 and 6 show that context effects are language-selective, affecting only the target language, but meaning-nonselective, affecting both contextually-appropriate and inappropriate meanings. The results show semantic context effects only within a language, such that only the relevant lexicon is affected by the sentence context. Both meanings of a within-language homophone are affected by the conceptually biasing context, but nontarget language activation is not controlled by conceptual bias in the target language. This pattern of results requires a model of bilingual word recognition in which the lexicons of the two languages are separate, but interact with a common phonological feature level, in order to give rise to nonselective access. BIMOLA can account for the current results: bottom-up lexical activation is

language-nonspecific, and the lexicons are not shared. A model like the BIA+ would not be able to account for the results because its lexicons are integrated, and any top-down context effects cannot affect languages separately. In contrast, BIMOLA accounts for language-selective semantic level context effects by allowing global language information to play a role in activation of words in each language network separately.

A second issue is that the baseline activation of the nontarget competitors may play a role in measuring context effects. One concern about the absence of context effects in Experiment 6 is that the level of activation of the Spanish Competitor may have been artificially low and susceptible to floor effects. For example, in Experiment 2, the shape competitor of the alternate homophone meaning attracted up to 35% of the looks in a 100 ms time interval, but in Experiment 6, the maximum was 23%. This 12% difference may have caused a disadvantage for activation of the nontarget language competitors, preventing measurement of real context effects. Experiment 7 attempted to address this last concern by incorporating Spanish as the target language.

### 5.3 Experiment 7: Spanish Context

Experiment 6 may have produced an overall reduced number of looks to the nontarget language competitor because the monolingual English environment may have rendered any effects of context to be too small to measure. The environment in which we have tested the participants (English-speaking country, city, university, experimenters, etc.) is inherently biased towards English. We can take advantage of this bias by reversing the target language to Spanish. With this configuration, the nontarget phonological competitor (now English) may gain overall increased activation because of its dominant status in the environment. With this change, I expect the competitor to have

higher detectable levels of activation, which may in turn allow any real effects of context to be detected.

Alternatively, if the reduced number of looks in Experiment 6 were due to reduced phonological overlap (phonological competitors averaged 353 ms overlap with the target, compared to 527 ms in Experiment 2), reversing the target language may not increase fixations. A future experiment would need to test whether phonological overlap is a factor in increasing fixations. The use of interlingual homophones would provide complete phonological overlap.

### *5.3.1 Methods*

#### *Participants*

Fourteen Spanish-English bilinguals (average age 20.9, 5 males, 9 females) who became fluent in both Spanish and English before age 8 were paid for participation. All participants had normal or corrected vision. Participants completed a language background questionnaire (see Appendix D).

#### *Materials*

The fourteen target word pairs from Experiments 5 and 6 are identical to those in the current experiment. Two lists of Spanish sentences, distinguished by linguistic context condition, were created for each of the fourteen Spanish Targets. In the Neutral-Imperative context condition, participants heard an instructional sentence, in which the sentence does not carry additional conceptual information other than the target word itself (e.g., “Mira la *muñeca*”). In the Conceptually-Biasing context condition, participants heard a sentence context that semantically constrained the target toward the Spanish word’s meaning (e.g., “María se enojó muchísimo cuando Sara le quitó *la muñeca*”

“Mary got especially mad when Sara stole her doll”). No lexical associates were used in the sentence, in order to exclude bottom-up lexical priming as a factor in activation of the target. A native Spanish speaker from Colombia recorded the sentence contexts. Colombia was judged to be the least region-specific country in pronunciation of Spanish.

Similar to Experiments 5 and 6, four objects appear at target word onset: the Spanish Target (e.g., *muñeca*), the English Phonological Competitor (e.g., *moon*), and 2 unrelated fillers. Every participant heard each Spanish Target once, in either the Conceptually-Biasing or Neutral-Imperative context conditions. Items were counterbalanced so that each item was presented in each condition an equal number of times.

#### *Procedure and Equipment*

The procedure was identical to that of Experiment 6, except only one block order was used: participants saw Neutral-Imperative context trials before the Conceptually-Biasing context trials. Because time constraints permitted only running half the number of participants, only one block was used. This particular block was chosen because the Neutral-Imperative context would be most neutral if preceded with no trials than if preceded by Conceptually-Biasing context trials.

#### *5.3.2 Results*

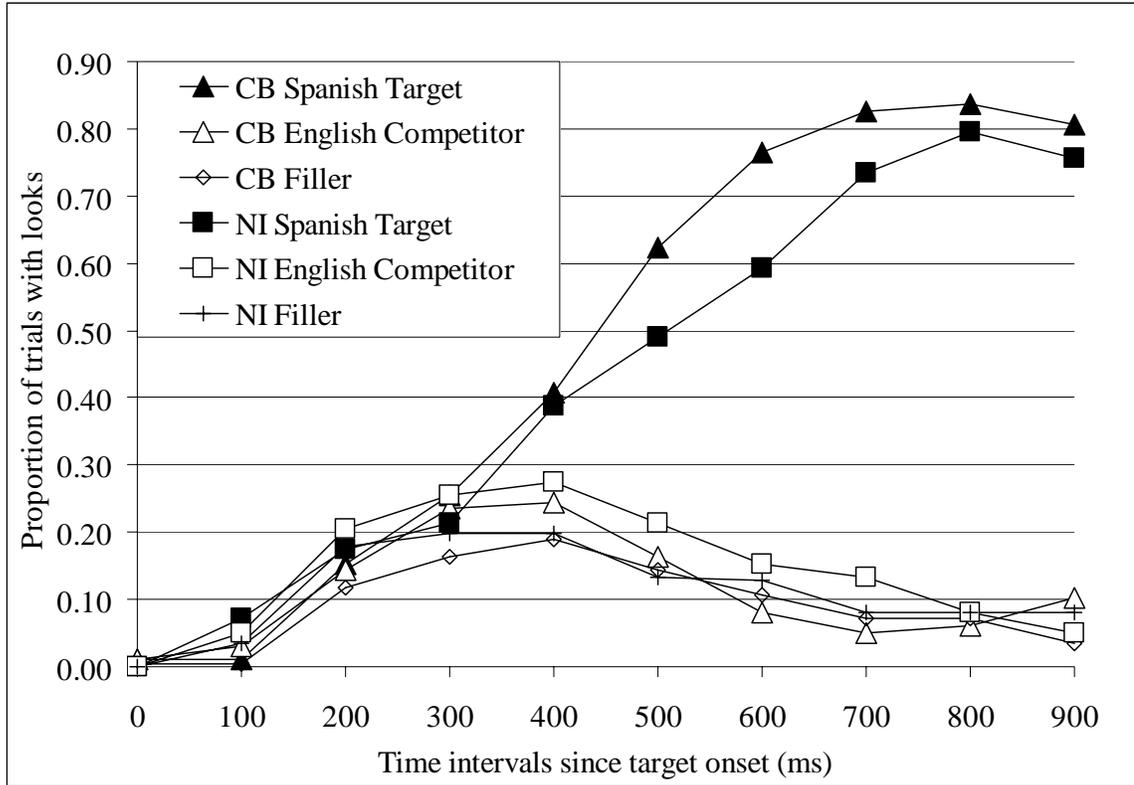
There were two critical pictures on each trial, the Spanish Target and the English Competitor. The three eye movement measures analyzed include the following:

1. First run dwell time on each of the critical pictures

2. Visual bias towards English competitors, measured by log gaze probability ratios to Spanish competitor and filler pictures from target word onset until 1000 ms after target onset
3. Context effects on the Spanish Target and English Competitor

Figure 10 presents the proportion of looks to all four critical pictures during each 100 ms interval after target onset for the two lists. Participants started to make fixations at 100 ms, and looks to the Spanish targets digress from the Competitor at around 400 ms. The English competitor seemed to have a slight advantage at around 300 to 400 ms. It was expected that the change in target language from English to Spanish would increase the overall amount of fixations to the English Phonological Competitor in this experiment. However, this does not seem to be the case.

Figure 10. Experiment 7 time course of probability of fixations on critical pictures and fillers at each 100 ms interval from target onset, with Conceptually-Biased context (CB) represented with triangles and Neutral-Imperative Context (NI) represented with squares. The first interval is 0-99 ms after target onset.



### First run dwell time

First run dwell times were analyzed in order to evaluate initial processing time for each of the fixated objects. The average first run dwell time for critical objects in each context condition in milliseconds, with standard errors in parentheses, were as follows: Neutral-Imperative context: Spanish Target: 665(18), English Competitor: 213(8), Fillers: 207(6); Conceptually-Biasing context: Spanish Target: 656(17), English Competitor: 219(10), and Fillers: 192(5).

In order to determine whether the nontarget English language was activated at above chance levels, first run dwell times to the English Competitors were compared to average first run dwell times to the unrelated Filler Objects. A mixed model treating

object type (English Competitor or Filler) and context type (Neutral-Imperative or Conceptually-Biased) as fixed factors and participants and items as random factors found a main effect of object type ( $F(1148) = 4.516, p < .05$ ). There was no effect of context condition ( $F < 1$ ) and no interaction between factors ( $F(1123) = 2.237, p > .10$ ).

This pattern of results replicated Experiment 6 and suggests that the nontarget language, represented by the English Competitor, was activated at levels higher than chance, without influence from the top-down context.

#### *Visual Bias to English Competitors*

In order to evaluate the time course of nontarget English language activation, log gaze ratios measured visual bias to the English Competitors compared to filler objects. If English Competitors were activated more than unrelated filler objects, this would be evidence for higher activation than expected by chance. Mixed models treating log-ratios (log-ratios vs. 0) and context condition (Neutral-Imperative or Conceptually-Biasing) as fixed factors, and items or participants as random factors, are reported in Table 7. There were main effects of log-ratio by both participants and items at 300 and 700 ms. This effect is not as robust, but is consistent with, the effects reported in Experiment 6. There was a weak interaction of sentence context at 700 ms, but only by participants ( $F_1(2,12) = 5.44, p < .05, F_2$ : no value).

Table 7

*Experiment 7 log ratios of visual bias towards English competitors over fillers for each context condition, including mixed model effects in 100 ms time intervals from target onset*

Bin	Log-ratios by Context Type		Log-ratio Main Effects			
	Neutral	Conceptually Biasing	dfs	F1	dfs	F2
200	0.13	0.20	1,27	3.58 <sup>m</sup>	1,11	1.93
300	0.25	0.36	1,44	9.11**	1,18	7.37*
400	0.33	0.26	1,39	6.24*	1,26	2.87
500	0.48	0.13	1,32	4.89*		<1
600	0.18	-0.27	1,15	4.44 <sup>m</sup>	1,18	1.68
700	0.49	-0.34	1,6	7.87*	1,6	7.75*
800	0.00	-0.15	1,12	7.06*	1,3	5.34
900	-0.47	1.05	1,3	1.08	1,4	1.87

<sup>m</sup> $p < .10$ , \* $p < .05$ , \*\* $p < .01$ , \*\*\* $p < .001$

*Semantic Context Effects on Targets and Competitors*

To evaluate whether the semantic context differentially activated the target language and nontarget language, I compared the proportion of looks to the Spanish Target and the English Competitors in the two context conditions over time. In order to explore whether context effects differed between languages, a mixed model treating context condition (Neutral-Imperative or Conceptually-Biasing), and language type (Spanish Target or English Competitor) as fixed factors, and items and participants as random factors, was performed for each 100 ms time interval. The interaction of context and language type was significant from the 500 through the 700 ms intervals (500 ms:  $F(1,375) = 4.28$ ,  $p < .05$ ; 600 ms:  $F(1,375) = 9.68$ ,  $p < .01$ ; 700 ms:  $F(1,375) = 6.02$ ,  $p < .05$ ). Paired comparisons revealed context effects only within Spanish Targets at 500 and

600 ms (500 ms:  $F(1, 375) = 4.47, p < .05$ ; 600 ms:  $F(1, 375) = 9.72, p < .01$ ), with a marginal effect at 700 ms ( $F(1, 375) = 3.37, p < .10$ ), but no context effects within English Competitors at any interval (500 ms:  $F < 1$ ; 600 ms:  $F(1,375) = 1.65, p > .10$ ; 600 ms:  $F(1,375) = 2.66, p > .10$ ). Thus, context differentially affected the target and nontarget languages, as it boosted activation of the target language, and did not affect the nontarget language.

### 5.3.3 Discussion

English competitors had longer first run dwell times than expected by chance, and the nontarget language was activated in both context conditions, replicating the results of Experiment 6. Although the activation of the competitor over time was less robust in Experiment 7, the same pattern of activation arose: The nontarget language competitor attracted more looks than expected by chance, regardless of the context in which the target word was spoken. Even though the context conceptually biased only the interpretation of the target word, the nontarget competitor remained active. This replication confirmed the results of Experiment 6 that context affected the target language but not the nontarget language.

The use of Spanish as the target language in Experiment 7 was intended to increase the probability of looks to the nontarget English competitor. The peak proportion of looks in a 100 ms interval did increase in Experiment 7, 28%, up from 23% in Experiment 6, however this difference did not affect the pattern of results. Context still was unable to modulate the nonselective activation of the nontarget phonological competitor. An alternative explanation for the low fixation probabilities is the shorter phonological overlap of the phonological competitors (353 ms, compared to 527 ms

overlap for homophones in Experiment 1 and 2). Additional experiments using interlingual homophones, which overlap completely in phonology, may test this hypothesis.

Although the conceptually-biasing sentence contexts in Experiments 6 and 7 constrained the meaning of the target words towards the meaning in the target language only, they did not prevent the nontarget phonological competitors, which were conceptually and visually unrelated to the target, from being activated. Instead, the nontarget language competitor was activated at higher levels than chance, no matter the type of context preceding it. This paradigm was able to reveal robust nontarget language activation as early as 200 ms, which is simultaneous with the earliest planned fixations. However, this early activation is not subject to top-down influences, suggesting an autonomous language non-selective account of bilingual word recognition.

Comparing the current within-language and between-language visual world experiments, eye fixations to nontarget competitors in both experiments, either to shape competitors (Experiments 1 and 2) or word-initial phonological competitors (Experiments 5, 6, and 7), were activated at early time intervals. The within-language and between-language experiments, however, diverge in the way context affected the activation of the nontarget competitor. Conceptually-biasing context did modulate the activation of the inappropriate meaning of a homophone within a language (Experiment 2), but did not modulate inappropriate nontarget language activation (Experiments 6 and 7).

One explanation of the difference between the within-language experiment and between-language experiments is the amount of phonological overlap between the

competitors and the target. The competitors in the within-language experiment overlapped entirely in phonology with the target, as they were homophones. The phonological competitors in the between-language experiments, however, overlapped only with the first few phonemes with the target. This difference may have contributed to the difference in overall number of looks to the competitor. With a low probability of looks to the competitor, it is more difficult to evaluate context effects on nontarget language activation. A future study that examines interlingual homographs, which overlap entirely in phonology, would allow us to better assess context effects on competitors in the visual world paradigm.

Another explanation for the difference in contextual efficacy is that bilinguals are efficient in selecting the relevant language in different situations (Bialystok, 2001, 2005; Green, 1998; Kroll & DeGroot, 1997). Bilinguals have been found to have better attention and cognitive control than monolinguals (Bialystok, 2001). This advantage over monolinguals is attributed to life-long experience allocating attention between two languages and inhibiting irrelevant languages. Although both monolinguals and bilinguals go through similar processes during word recognition, it is executive control during language processing that is enhanced for bilinguals. With enhanced cognitive control to attend to the relevant language, bilinguals may be more skilled in using top-down semantic context in a language-specific manner. If this is the case, only the relevant lexicon is affected by the sentence context, so both meanings of a homophone in English would be affected by a conceptually-biasing English context. In contrast, a conceptually-biasing Spanish context would not affect the bottom-up activation of the nontarget English language. This explanation is in accordance with a model of spoken word

recognition with nonselective language activation from bottom-up input, but language-selective influences from top-down input, such as BIMOLA.

If the suppression of irrelevant languages in bilinguals is generalized to other aspects of language processing, such as within-language processing, bilinguals may also have an advantage in suppressing irrelevant homophone meanings, similar to Experiment 2. Bilinguals may be better able to inhibit the inappropriate meaning of a homophone in a subordinate-biased context. Another way to compare determine whether semantic context differentially affects within-language and between-language competitors for bilinguals is to investigate the effects of neutral and conceptually-biasing context on the target, along with a within-language phonological competitor and a between-language phonological competitor. Previously, Marian et al. (2003) used a similar arrangement in the visual world paradigm to test within-language and between-language phonological competitors in neutral contexts only. They tested a condition in which targets appeared with within-language competitors or between-language competitors, and also a condition in which both the within-language and between-language competitor were displayed with the target. Both within-language and between-language competitors were activated higher than chance levels, and the level of activation did not differ across languages. However, they did not examine conceptually biasing context, which would be crucial for testing whether semantic context affects only within-language competitors but not between-language competitors. This test would confirm whether semantic context is language-selective, such that it differentially affects nontarget activation in multiple lexicons. If the within-language competitor and between-language competitor both activate to the same degree in neutral contexts, but the conceptually-biasing context suppresses only the

within-language competitor, this would be strong evidence for language-selective contextual modulation.

## CHAPTER 6

### GENERAL DISCUSSION

This set of studies attempted to elucidate the effects of top-down sentential context on word recognition, not only within one language, but also across languages. The evidence and analyses provided in this project provide insight specifically for theories of lexical ambiguity resolution and bilingual word recognition, but their interpretation applies to word recognition in general. In this series of experiments, I measured activation of within-language and between-language competitors in both the auditory visual world paradigm and the visual naming paradigm to detangle the debates over the time course and extent of context effects on word recognition.

#### 6.1 Summary of Experiments

##### *6.1.1 Context and Frequency Effects on Homophone Meaning Activation*

In Experiments 1 and 2, I explored context and frequency effects on homophone meaning activation in the visual world paradigm. In Experiment 1, using neutral imperative sentence contexts, both the pictured referent meaning of the homophone and a shape competitor of the alternative meaning of the homophone competed for attention following the spoken homophone. Importantly, I found dominance effects on looks to Shape Competitors when an Actual Referent was simultaneously pictured. Dominant meanings were activated more strongly than the subordinate meanings, as seen in the high number of looks to the dominant Shape Competitors. Secondly, although

subordinate meaning Shape Competitors received fewer overall looks than the dominant meaning Shape Competitors, they nonetheless received above-chance attention, despite the presence of an Actual Referent for the dominant meaning. Both effects are somewhat surprising, given that shape competitors had no connection to the spoken homophone, except that they were visual competitors of the alternate meaning. As such, these results add to the growing body of shape competitor findings in the visual world paradigm indicating that shape competitors provide an unobtrusive but sensitive index of lexical activation (Dahan & Tanenhaus, 2005; Huettig et al., 2004; Huettig & Altmann, 2007).

In Experiment 2, I demonstrated that top-down processing from sentential context can influence the pattern of activation of multiple meanings of a homophone at early time intervals: Subordinate-biasing context serves to both boost activation of the subordinate meaning of the homophone and decrease activation of the dominant meaning, although the dominant meaning is still activated more than expected by chance. This provides evidence that multiple access of homophone meanings still occurs, even when the biasing sentential and visual context allows only one interpretation of the homophone, which is consistent with the results of Huettig and Altmann (2007), previous reading studies showing the Subordinate Bias Effect even during strongly biased contexts, and Reordered Access (Binder, 2003; Binder & Rayner, 1998; Kambe et al., 2001; Pacht & Rayner, 1993; Rayner et al., 1994, 2006; Sereno et al., 1992, 2006).

Multiple homophone meaning access, however, is inconsistent with the predictions of Selective Access models. Dominant meaning activation should be eliminated in strongly subordinate-biasing contexts. As discussed above, both the

normative data and the large, immediate effects of contextual bias suggest that the current subordinate-biased contexts were indeed strongly biasing.

In contrast, the finding that the subordinate-biasing context decreases activation of the dominant meaning is not consistent with a strict version of Reordered Access that assumes that contextually inappropriate meanings are not influenced by disambiguating context (Duffy et al., 1988, 2001). This finding is, however, consistent with Selective Access accounts, where frequency, type of context and strength of context can influence homophone meaning activation (Martin et al., 1999). Neither a strict version of Reordered Access nor Selective Access is capable of accounting for all the findings in Experiment 2. A more appropriate approach may be a version of Reordered Access in which both variables, frequency and context, can modulate activation of each homophone meaning, but neither factor is able to completely dominate patterns of lexical activation. For balanced homophones, context may be strong enough to selectively activate a single meaning, but, for polarized homophones, the dominant meaning is likely to be activated, even in strongly subordinate-biased contexts, based solely on the strength of its form to meaning mapping. Although context can have a large influence on activation of each of the homophone meanings, activation of a strongly dominant meaning probably cannot be completely overridden. An interactive model of this type would be able to account for the findings in Experiment 2.

#### *6.1.2 Motivational Effects on Homophone Meaning Activation*

The theory of *Reordered Access* is often supported by evidence showing that a homophone's dominant meaning remains active during subordinate biasing contexts, as in Experiment 2. However, this interpretation of the evidence has relied on the implicit

assumption that participants attended to and comprehended the strongly subordinate-biasing contexts. I was concerned that participants may not have fully comprehended the context. Incomplete comprehension may have allowed the dominant meaning to be active during subordinate biasing contexts, providing misleading support for *Reordered Access*.

In order to explore whether incomplete comprehension was the cause of dominant meaning activation in subordinate biasing contexts, I attempted to motivate participants to attend and comprehend sentence contexts to their highest capacity. Experiment 3 established the baseline activation of the dominant homophone meaning in a subordinate biasing context in a naming task, and resulted in a pattern of activation normally interpreted as evidence for *Reordered Access*. Experiment 4 explored whether incomplete comprehension was the cause of this pattern by attempting to motivate participants by adding monetary incentive, feedback and supervision to the naming task.

In Experiment 4, I demonstrated that motivational factors can affect overall performance in the naming task, such as increasing comprehension accuracy and decreasing response latency. Motivation affected comprehension of the sentence contexts, but its effects on dominant meaning activation were mixed. Analyses of the interaction between contextual appropriateness and amount of probe facilitation seemed to support *Reordered Access*. However, paired comparisons showed significant facilitation for contextually appropriate probes, but not for inappropriate probes. The pattern in the paired comparisons is entirely consistent with *Selective Access*.

Comprehension of the sentence contexts in Experiment 4 was examined by comparing average individualized word-by-word reading times on the sentence contexts. Because reading times varied widely, reading times could be correlated with the amount

of selective activation of the contextually-appropriate probes. In fact, it was found that slower readers were more likely to selectively activate the appropriate meaning of the homophone. Slower readers may have paid more attention to the sentence context, deliberately concentrating on comprehension of the sentence. This is encouraging for proponents of Selective Access. This finding suggests that if more effective ways of motivating participants to pay attention to the sentence context were employed, future studies would be more likely to yield patterns of data supporting Selective Access.

### *6.1.3 Context Effects on Bilingual Language Activation*

The Spanish-English bilingual experiments sought to extend previous research on multiple language activation during spoken word recognition and also to explore the effects of top-down sentential context on nonselective language access. Participants heard either imperative sentences like *Look at the moon* or conceptually biasing contexts like *Jimmy has always been curious about the vastness of our galaxy, and was most interested in the moon* in English or Spanish as the carrier language.

Nontarget language activation was indeed found in Experiments 5-7, demonstrating as early as 200 ms that multiple languages are activated, in both English and Spanish language contexts. This is the first demonstration of the time course of bilingual language activation in the visual world. Despite having only a mean of 2.4 overlapping initial phonemes, the nontarget competitor elicited more fixations than chance. This bilingual cohort activation is similar to activation found in monolingual word processing. For example, Allopenna et al. (1998) used the visual world paradigm to investigate cohort effects on monolingual word recognition. They found that word-initial cohorts, as well as rhyme cohorts both are activated, as evidenced by eye movements

traced over time. The current evidence suggests that bilingual word recognition in neutral contexts is similar to monolingual word recognition, except that the lexicon is greatly multiplied. However, it remains to be tested whether the activation of within-language or between-language competitors have the same activation pattern. Pitting the competitors together on a trial could elucidate the time course of each language's activation.

Experiments 6 and 7 demonstrated that no matter whether the sentence context was conceptually-biasing or neutral, the nontarget language was activated. Although the conceptually biasing contexts were constructed to constrain the meaning exclusively to the target language, it did not have any reliable effects on nontarget meaning activation. Although the context did boost the activation of the target word, it did not limit the activation of the nontarget competitor.

The lack of context effects on nontarget language activation is consistent with previous reading studies (Duyck et al., 2007) and the BIMOLA. However, it is surprising, given that semantic context plays a role in lexical access in the monolingual literature (Duffy et al., 1989; Simpson et al., 1989; Stanovich & West, 1979, 1981, 1983; West & Stanovich, 1982) and in lexical ambiguity resolution, where semantic context plays a role within 200 ms of homophone offset (Seidenberg et al., 1982; Sereno et al., 2003; Tabossi, 1988; Tabossi & Zardon, 1993; Tanenhaus et al., 1979). The absence of context effects on the nontarget language is also inconsistent with the predictions of the BIA+ model of bilingual word recognition, which assumes that top-down linguistic context like the conceptually biasing context in the current experiment should affect both the target and nontarget languages (Dijkstra & Van Heuven, 2002).

One explanation for the difference in contextual modulation of target and nontarget languages is that bilinguals are specially trained to separate information processing in different languages (Bialystok, 2001, 2005; Green, 1998; Kroll & DeGroot, 1997). As described previously, the majority of evidence shows that multiple languages are active when a bilingual processes any of their languages. Bilinguals have an additional problem compared to monolinguals because their lexicons are increased, due to multiple languages. Not only does the lexicon increase, but phonological neighborhoods also increase. Green (1998) explains that bilinguals are not considerably handicapped by multiple languages because they have developed a skill to reactively inhibit the irrelevant language. This reactive inhibition may allow bilinguals to have better cognitive control of their languages, allowing them to have top-down control selective to the target language. Whether or not this executive function ability is generalized to within-language inhibition of irrelevant meanings is an empirical question. This hypothesis can be tested by contrasting neutral and conceptually-biasing context effects on both within-language and between-language phonological competitors of a target. This test would confirm whether semantic context is language-selective, such that it differentially affects nontarget activation in multiple lexicons. If the within-language and between-language competitors both activate to the same degree in neutral contexts, but the conceptually-biasing context interacts to suppress only the within-language competitor, this would be strong evidence for language-selective contextual modulation.

## 6.2 Language-Nonselective and Selective Access in Word Recognition

This set of studies examined top-down contextual influences on word recognition both within-language and between-languages. In order to incorporate the current within-language and between-language experiments into a coherent model of word recognition, the results are interpreted based on current theories of bilingual word recognition: the Bilingual Interactive Activation Model (BIA+) (Dijkstra & Van Heuven, 2002) and the Bilingual Interactive Model of Lexical Access (BIMOLA) (Grosjean, 1988, 1997; Lewy & Grosjean, in preparation, as cited in Thomas & Van Heuven, 2005), and also the Reordered Access (Duffy et al., 1998, 2001) and Selective Access (Martin et al., 1999) theories of lexical ambiguity resolution.

### *6.2.1 Bilingual Interactive Activation + (BIA+)*

The BIA+ is a model of bilingual word recognition that assumes that lexical access is nonselective in nature. The architecture is similar to McClelland and Rumelhart's (1981) Interactive Activation Model, but incorporates orthographic, phonological, semantic, and language node representations in the word identification system. Nonselective language access is achieved by interconnectivity between integrated lexicons of different languages at the word level. A layer of semantic nodes influences word nodes. BIA+ predicts that conceptually-biasing contexts interact with word identification. The BIA+ additionally assumes that context effects are nonselective, such that context effects do not only influence one, but multiple languages. Thus, the model is not only language-nonselective with respect to bottom-up lexical access, but also language-nonselective with respect to top-down linguistic context.

### 6.2.2 Bilingual Model of Lexical Access (BIMOLA)

The BIMOLA (Grosjean, 1988, 1997; Lewy & Grosjean, in preparation, as cited in Thomas & Van Heuven, 2005) is based on the TRACE model of spoken word recognition (Elman & McClelland, 1986) and also assumes nonselective activation of words in two languages. Features excite and inhibit phonemes in both languages in parallel, but the phonemes interact with the word level only within the respective language. The phonemes and words have stores that are distinct for each language, and the two languages do not have direct connections with each other. Global language information, such as language mode, language background, and higher linguistic information affect word level activation, and affect each language network separately. Thus, semantic context effects are predicted to be language-specific.

### 6.2.3 Reordered Access

The two theories of lexical ambiguity resolution differ in predictions for fate of the dominant meaning when the context supports the subordinate meaning. *Reordered access* assumes that when reading a homophone, all meanings of homophones are made available, ordered by meaning frequency and contextual fit (Duffy et al., 1998, 2001). “Prior disambiguating context does affect the access process by increasing the availability of the appropriate meaning without influencing the alternative meaning” (Duffy et al., 1988, p. 431). Reordered Access would predict an above-chance number of fixations on the dominant competitor during subordinate biased context in the visual world paradigm, and dominant meaning facilitation compared to controls in the naming paradigm. Although Reordered Access assumes nonselective activation of multiple meanings, it assumes selective influence of context.

#### 6.2.4 *Selective Access*

*Selective Access* assumes that the activation of the meanings of an ambiguous word depends on several constraints: frequency, type of context, and strength of context; the combined influence of these variables determines the meaning accessed (Martin et al., 1999). The factors can interact, such that one factor can dominate over the other factors if sufficiently strong. If the context is sufficiently constraining toward the subordinate meaning, the dominant meaning should not be fixated above chance in the visual world paradigm, and should not be facilitated compared to controls in the naming paradigm. The subordinate-biasing context can serve to both boost activation of the subordinate meaning and limit activation of the dominant meaning. *Selective Access* would predict selective activation of a homophone meaning, and non-selective influence of context on word recognition.

#### 6.2.5 *Current Evidence*

There are three main pieces of evidence that need to be accounted for in a theory of word recognition for both monolinguals and bilinguals, as found in the current set of within-language and between-language experiments.

- 1) Multiple meaning activation of homophones and between-language phonological competitors, during both neutral and biasing contexts
- 2) Contextual modulation specific to the target language, but no modulation of nontarget language
- 3) Contextual modulation within-language, with appropriate-meaning facilitation and inappropriate-meaning inhibition

Each of the models may be evaluated according to their consistencies and inconsistencies with the current data.

The nonselective nature of the BIA+, BIMOLA, and Reordered Access are consistent with 1). BIA+ assumes that the sublexical and lexical levels both involve an integrated lexicon, so multiple meanings in different languages can be activated. BIMOLA assumes that the phonological feature level excites and inhibits both of the languages in parallel. Reordered Access assumes that multiple meanings are always accessed, in order of frequency and contextual fit. Selective Access is not consistent with 1), because the strongly biasing context, as in Experiment 2, would be able to dominate word recognition, such that only the appropriate meaning is ever accessed. Overall, in order to account for multiple meaning access both within and between languages, there must be parallel bottom-up activation. Multiple representations should be activated nonselectively from the input, with respect to both multiple meanings and multiple languages.

Reordered Access would predict 2) because it assumes that only contextually-appropriate meanings are affected by context, so activation of nontarget languages would remain unaffected. BIMOLA also predicts 2) because it assumes that top-down influences of global language information affect each language network separately, which is consistent with contextual modulation of only the relevant language. BIA+ is not consistent with 2) because it allows for nonselective influence of the context on multiple languages. BIA+ would have predicted that nontarget language activation would also be affected by context. Selective Access would not predict 2) because it would assume that context interacts to facilitate appropriate and inhibit inappropriate meanings,

thus having inhibitory effects on the nontarget language. With regard to multiple language access, an appropriate model should allow context to selectively influence only the relevant language.

The direct connections between semantic context and word recognition make BIA+, BIMOLA and Selective Access consistent with 3). The BIA+ allows contextual modulation because semantic context is part of the word identification system and has direct excitatory and inhibitory effects on recognition. BIMOLA allows contextual influence on word activation in the relevant language network; for a monolingual, there is only one network. Selective Access assumes that context serves to both increase activation of appropriate meanings and decrease activation of inappropriate meanings. Reordered Access, however, is not compatible with 3), because it explicitly assumes that inappropriate meanings are not affected by context. Context should have direct effects on multiple meanings within a language. Although 2) requires that contextual constraints should be language-specific, 3) requires that contextual constraints be nonspecific with respect to multiple meanings.

In sum, the current set of experiments is consistent with model of word recognition that has the following characteristics: 1) bottom-up word recognition is nonselective with respect to which language is activated and also which meanings are activated, 2) top-down semantic context is language-selective, such that conceptually biasing sentence context has influence only on the relevant target language, 3) top-down semantic context is meaning-nonselective, such that both appropriate and inappropriate meanings can be modulated by context. The only model with these characteristics is BIMOLA.

### 6.2.6 BIMOLA Examples

The following is an example of how BIMOLA allows context to exclusively modulate the target language for a Spanish/English bilingual. Assume the input is the English sentence *Jimmy has always been curious about the vastness of our galaxy, and was most interested in the moon.* At the acoustic onset of each word, phonological features are activated, which in turn activate phonemes from both English and Spanish. With subsequent acoustic input, the phonemes in English activate English words, and the phonemes in Spanish activate Spanish words. Thus, cross-language cohort competitors are activated at each word, as long as the word's initial phonetic features are shared by words in both languages. The words activate their respective language networks. However, the English language network is activated more than the Spanish language network because fewer Spanish phonemes and words match the input.

Because bilinguals have the enhanced ability to attend to one language over another, it is possible that the global language information and higher linguistic information, such as semantic context, is used in a language-specific manner. Thus, semantic level information, such that the concepts “galaxy” and “vastness” act only on the English language network when the bilingual processes the English context. This attentional control of language allows for language-specific semantic effects. Finally, when the word *moon* is heard, both *moon* and *muñeca* are activated from bottom-up input because phonemes from both Spanish and English match the input. Because the bilingual has attended to the target English language network, top-down influence of semantic context is only open for English, and the meaning of *moon* is boosted, but the meaning of *muñeca* is not facilitated.

The following example explains how context modulates alternative meanings within a language. Assume the input is *The baker took out milk, eggs, and flour*. At the acoustic onset of each word, phonological features are activated, which in turn activate phonemes from English only for monolinguals (or both English and Spanish for bilinguals). With subsequent acoustic input, the phonemes in English activate multiple English words (and in Spanish for bilinguals). The English words activate the English language network (and the Spanish words activate the Spanish language network for bilinguals, but the Spanish language network remains less activated than the English language network because fewer Spanish phonemes match the input). . When the word *flour* is heard, both *flour* and *flower* are activated from bottom-up input (as well as *flaw*, *flew*, *fly*, *Florida*, etc. for a monolingual, and *flaca*, *flan*, *flecha*, etc. for a bilingual). Semantic information, such that the concepts “baker” and “milk” act on the word level (if bilingual, only on the attended language network). Top-down semantic context excites the word level. These excitatory connections facilitate the contextually appropriate meanings, and thus increase the within-level inhibition of contextually inappropriate meanings at the word level. Thus, the meaning of *flour* is excited, but the meaning of *flower* is inhibited.

In contrast to the BIA+, which assumes an integrated lexicon, the BIMOLA stores languages in separate networks. This design allows for multiple language networks to be activated to different degrees. It also allows for the language-nonselective nature of the bottom up input and the language-selective nature of the semantic context. The BIMOLA also applies to monolingual language activation because BIMOLA also works when only one language network is involved. BIMOLA shows how multiple meanings can be

activated both within languages and across languages. Thus, BIMOLA is a superior model that can account for the current data for both monolingual and bilingual language activation.

## Appendix A

### Critical Stimuli for Experiment 1

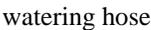
Critical Homophone	Dominant Actual Referent	Dominant Shape Competitor	Subordinate Actual Referent	Subordinate Shape Competitor
<b>bow</b>	 hunting bow	 hanger	 bowtie	 candy
<b>check</b>	 money check	 cutting board	 check symbol	 carpenter square
<b>fairy</b>	 fairy woman	 insect	 ferry boat	 sushi boat
<b>file</b>	 nail file	 ink pen	 office file	 accordion
<b>flower</b>	 flower blossom	 lollipop	 wheat flour	 pillow

Critical Homophone	Dominant Actual Referent	Dominant Shape Competitor	Subordinate Actual Referent	Subordinate Shape Competitor
glasses	 reading glasses	 handcuffs	 drinking glasses	 candles
horn	 French horn	 shell	 animal horn	 ice cream cone
letter	 written letter	 playing card	 alphabet letter	 church cross
nails	 hand nails	 lipstick	 hammer nails	 pencils
note	 written note	 framed painting	 music note	 ladle

<b>Critical Homophone</b>	<b>Dominant Actual Referent</b>	<b>Dominant Shape Competitor</b>	<b>Subordinate Actual Referent</b>	<b>Subordinate Shape Competitor</b>
<b>nut</b>	 nut in shell	 brain	 tool nut	 hexagonal boxes
<b>ring</b>	 wedding ring	 inner tube	 boxing ring	 sandbox
<b>stamp</b>	 letter stamp	 painting	 ink stamp	 joystick
<b>tank</b>	 army tank	 slide projector	 water tank	 pill

Appendix B

Additional Stimuli for Experiment 2

<b>Critical Homophone</b>	<b>Dominant Actual Referent</b>	<b>Dominant Shape Competitor</b>	<b>Subordinate Actual Referent</b>
<b>hose</b>			
<b>trunk</b>			

## Appendix C

Experiments 3 and 4 Sentence Context Paragraphs and Probes, Adapted from Vu et al.

(2000)

<u>Sentence Context Paragraph</u>	<u>Subordinate Probe</u>	<u>Dominant Probe</u>
The debutante sat by the door. She watched the ball.	DANCE	BOUNCE
The alligator saw the food. He came from the bank.	RIVER	VAULT
The botanist looked for a fungus. She investigated the bark.	TREE	GROWL
The sergeant left the jeep. He approached the base.	STATION	SAFE
The biologist searched the opening. He located the bat.	CAVE	BALL
The judge was lenient. He overlooked the battery.	ASSAULT	CAR
The chauvinist was obnoxious. He deserved the belt.	HIT	PANTS
The assistant proposed the idea. He wrote the bill.	GOVERNMENT	PAY
The chairman started the argument. He divided the board.	DIRECTORS	PLANK
The groomsman looked in the mirror. He straightened the bow.	TIE	ARROW
The detective searched the room. He spotted a bug.	MICROPHONE	INSECT
The gardener dug a hole. She inserted the bulb.	FLOWER	LIGHT
The queen ignored the advice. She rejected the cabinet.	MINISTER	KITCHEN
The harvester gathered the crop. He delivered the cane.	SUGAR	WALKING
The brewer started a bottling company. He manufactured the cap.	TOP	HAT
The shopper disliked the poem. She exchanged the cards.	GREETING	PLAYING
The counsel left the room. He finished a case.	LAWSUIT	BEER
The reviewer was disappointed. She hated the cast.	ACTORS	BROKEN
The commander counted the fatalities. He reviewed the charge.	ATTACK	CREDIT
The sailor shoveled the sand. He covered the chest.	TREASURE	BODY
The duchess accepted the gift. She knew the count.	NOBLEMAN	MATH
The gambler wanted an ace. He searched the deck.	PACK	SHIP
The groundskeeper was compulsive. He measured the diamond.	BASEBALL	RING
The graduate wanted a car. She saved the dough.	MONEY	FLOUR
The yardman checked the weather. He anticipated the fall.	LEAVES	DOWN
The referee had miscounted. He rechecked the field.	SPORTS	FARM
The beautician was not finished. She needed the file.	NAIL	CABINET
The resident noted the broken elevator. She counted the flights.	STAIRS	PLANE
The opponent awaited the signal. He held the foil.	SWORD	ALUMINUM
The kidnapper prevented the scream. He used the gag.	MOUTH	JOKE
The woodsman was hunting. He observed the game.	ANIMAL	PLAY
The comedian was offensive. She noticed the glare.	STARE	SUN
The barmaid dropped the tray. She broke the glass.	CUP	WINDOW
The cook was thrifty. He saved the grounds.	COFFEE	DIRT
The guest was cheating. She hid her hand.	CARDS	FINGERS
The poacher reached for his kill. He grabbed the horn.	DEER	BLOW
The businessman lived from a suitcase. He carried the iron.	SHIRT	STEEL
The cabby knew the streets. He bypassed the jam.	STUCK	TOAST
The pusher lied about the product. He exaggerated the kick.	STIMULATION	PUNT

Sentence Context Paragraph

The zookeeper mixed the grain. He fed the kid.  
 The pianist flipped the page. She tore the leaf.  
 The mayor helped the group. He organized the lobby.  
 The hippie changed his appearance. He cut the lock.  
 The researcher transformed the data. He used a log.  
 The bishop arrived on time. He held the mass.  
 The boyscout searched his supplies. He found a match.  
 The dermatologist examined the skin. She observed the mole.  
 The manicurist was in a hurry. She bent the nail.  
 The accountant subtracted the expense. He showed the net.  
 The guitarist adjusted the string. She changed the note.  
 The surgeon noted the damage. He refused the organ.  
 The ranger loved wildlife. He raised the pack.  
 The knight watched the procession. He identified the page.  
 The caller won the contest. He received the pass.  
 The librarian found the quote. He marked the passage.  
 The farmer hated the smell. He emptied the pen.  
 The singer raised his voice. He changed the pitch.  
 The coach changed the lineup. He bumped the pitcher.  
 The tycoon attended the opening. He named the plant.  
 The screenwriter knew the lines. He recollected the play.  
 The writer changed the setting. He developed the plot.  
 The headwaiter scanned the list. He recommended the port.  
 The husband roasted the chicken. He burned the pot.  
 The woman reflected on her childhood. She preferred the present.  
 The victim testified in court. He recognized the quack.  
 The gunner saw the target. He adjusted the range.  
 The boss mailed the invoice. She kept the record.  
 The trader needed furs. He checked the reservation.  
 The nurse hated the alarm clock. She modified the ring.  
 The waitress looked at the menu. She suggested the roll.  
 The healer entered the chamber. He examined the ruler.  
 The bully met his match. He lost the scrap.  
 The defendant listened in silence. She heard the sentence.  
 The supervisor was flexible. He switched the shift.  
 The patient hated needles. He prevented the shot.  
 The homesteader needed a good crop. He wanted a shower.  
 The paramedic stocked the supplies. He stored the sling.  
 The intern opened the wound. He removed the slug.  
 The cardsharp wanted to trade. He offered the spade.  
 The amateur wanted to win. She needed a spare.  
 The maid cleaned the house. She smoothed the spread.  
 The upholsterer examined the chair. She missed the spring.  
 The shepherd was terrified. He dropped the staff.  
 The agent was ecstatic. He discovered a star.  
 The hillbilly was loafing. He chewed the straw.  
 The governor recommended the compromise. He overruled the strike.

Subordinate Probe

GOAT  
 SHEET  
 LEGISLATIVE  
 HAIR  
 ARITHMETIC  
 CHURCH  
 FIRE  
 FACE  
  
 POLISH  
 REMAINDER  
 TONE  
 ANATOMY  
 WOLF  
 SERVANT  
 TICKET  
 BOOK  
 PIG  
 FREQUENCY  
 CATCHER  
 FACTORY  
 ACT  
 NOVEL  
 WINE  
 PAN  
 PAST  
  
 DOCTOR  
 DISTANCE  
 ORGANIZE  
 INDIAN  
 LOUD  
 BUN  
 KING  
 FIGHT  
 JAIL  
 WORK  
 ARM  
 RAIN  
 CAST  
 BULLET  
 ACE  
 STRIKE  
 BED  
 COIL  
 POLE  
 MOVIE  
 HAY  
 UNION

Dominant Probe

CHILD  
 MAPLE  
 MOTEL  
 KEY  
 WOOD  
 WEIGHT  
 TOGETHER  
 RODENT  
  
 HAMMER  
 MESH  
 MEMO  
 PIANO  
 BACK  
 BOOK  
 FOOTBALL  
 WAY  
 WRITE  
 THROW  
 CONTAINER  
 GREEN  
 GAME  
 GROUND  
 HARBOR  
 MARIJUANA  
 GIFT  
  
 DUCK  
 STOVE  
 ALBUM  
 HOTEL  
 DIAMOND  
 TUMBLE  
 MEASURE  
 GARBAGE  
 GRAMMAR  
 GEAR  
 GUN  
 BATH  
 SHOT  
 SNAIL  
 SHOVEL  
 TIRE  
 BUTTER  
 SUMMER  
 FACULTY  
 SKY  
 SIP  
 OUT

Sentence Context Paragraph

The internist was puzzled. He analyzed the stroke.  
The wrestler needed a break. He got the tag.  
The mortician applied the make-up. He touched the temple.  
The vet examined the ear. He noticed the tick.  
The sportscaster announced the record. He included the tie.  
The best man rehearsed his lines. He prepared the toast.  
The toymaker carved the wood. He made the top.  
The animal felt an itch. He scratched his trunk.  
The cardiologist found the problem. He repaired the vessel.  
The skier prepared for the jump. He pictured the wake.

Subordinate Probe

HEART  
TOUCH  
HEAD  
FLEA  
DRAW  
DRINK  
SPIN  
ELEPHANT  
BLOOD  
WAVE

Dominant Probe

SWIM  
LABEL  
CHURCH  
CLOCK  
BOW  
BREAD  
CLIMB  
CAR  
NAVY  
FUNERAL

## Appendix D

### Bilingual Participant Profiles

	<u>Experiment 5</u>		<u>Experiment 6</u>		<u>Experiment 7</u>	
	<u>Spanish</u>	<u>English</u>	<u>Spanish</u>	<u>English</u>	<u>Spanish</u>	<u>English</u>
Age when acquired	0.7	4.1	1.6	3.3	0.5	4.2
Age when fluent	3.5	7.2	6.3	6.3	3.1	8.2
Age when began reading	5.9	5.9	6.4	5.8	5.1	5.9
Age when fluent reading	8.5	7.3	8.4	7.9	7.5	9.1
Years in country spoken	12.23	13.82	9.5	16.2	7.5	14.3
Years in family spoken	21.53	9.90	18.2	15.3	20.2	10.1
Years in school spoken	11.63	14.55	9.7	16.2	8.3	13.8
<u>Level of proficiency, on a scale of zero (none) to 10 (Perfect)</u>						
Speaking	9.0	8.7	8.4	9.1	8.8	9.1
Understanding	9.2	9.2	9.0	9.4	9.4	9.5
Reading	8.5	8.8	7.8	9.3	8.4	9.4
<u>How much did the following factors contribute to your learning, on a scale of zero (not a contributor) to 10 (most important contributor)</u>						
Interacting with friends	5.7	7.9	6.0	7.7	6.2	9.0
Self-instruction	1.4	1.8	1.5	1.7	1.1	0.6
Family	9.8	2.8	8.4	5.9	10.0	4.6
TV	5.1	6.4	4.1	7.6	4.8	6.8
Reading	5.8	8.9	6.3	8.5	6.0	8.9
Radio	3.3	3.5	3.1	4.8	4.8	5.9
<u>To what extent are you currently exposed to the language, on a scale of zero (never) to 10 (always)</u>						
Interacting with friends	5.4	8.1	3.7	9.0	5.3	8.4
Self-instruction	6.0	5.3	4.1	7.5	5.1	7.9
Family	8.7	3.6	6.4	4.8	8.6	4.1
TV	4.7	8.3	3.1	9.2	3.6	8.6
Reading	4.3	7.0	2.0	8.0	3.8	8.6
Radio	1.4	1.4	1.1	1.6	0.7	0.7
<u>In your perception, how much of a foreign accent do you have, on a scale of zero (none) to 10 (heavy)</u>						
	0.6	2.7	2.0	1.7	1.6	2.6
<u>How frequently do others identify you as a non-native speaker based on your accent, on a scale of zero (never) to 10 (always)</u>						
	0.9	4.8	2.0	1.4	2.0	3.1

## Appendix E

### Stimuli for Experiments 5 and 6

<u>English Target</u>	<u>Spanish Phonological Competitor</u>	<u>English Translation</u>	<u>Conceptually-Biasing (Experiment 6 only)</u>	<u>Context</u>	<u>Sentence</u>
bell	la vela	candle			At the end of the school day, Alex knew that class was over because he heard the sound of the bell.
binder	la ballena	whale			Walter wanted to organize his school papers in his backpack, so he bought a binder.
bull	el buceador	diver			The farmer was having a quiet morning feeding the animals until he was trampled by the bull.
cherry	el chaleco	vest			After adding a dollop of whipped cream to the mouth watering dessert, Janice topped it off with a cherry.
eagle	la iglesia	church			The hiker stopped to rest on a rock and spotted something flying in the distance that looked like an eagle.
fan	el fantasma	ghost			The air inside the house was really hot and humid, so Teresa decided to turn on the fan.
flag	la flecha	arrow			Because the weather was dangerous, no one could go outside to take down the flag.
knee	la nina	girl			Nathan was hurrying up the stairs when he accidentally slipped and bumped his knee.
moon	la muñeca	doll			Jimmy has always been curious about the vastness of our galaxy, and was most interested in the moon.
newspaper	la nube	cloud			On Sunday morning, Tim's dad sat in the kitchen with his plate of bacon and eggs and enjoyed the newspaper.
onion	el anillo	ring			After Julie came home from hours of shopping at the produce store, she realized that she forgot to buy an onion.
orange	la oreja	ear			To make his own smoothie, Devon needed a blender, a cup of plain yogurt, ice cubes, and one orange.
ornaments	las hormigas	ants			In order to dress up the Christmas tree, Ann bought a set of eyecatching and fancy ornaments.
soap	el sobre	envelope			Jill was out playing in the mud, so when she came back in the house, she had to rub her hands with soap.

## Appendix F

### Stimuli for Experiment 7

<u>Spanish Target</u>	<u>English Translation</u>	<u>English Competitor</u>	<u>Conceptually-Biasing Context Sentence (Spanish)</u>	<u>English Translation</u>
la vela	candle	bell	Hubo un apagón ayer por la noche, así que Andrés no pudo hacer su tarea en la oscuridad sin una vela.	There was a blackout last night, so Andy couldn't do his homework in the darkness without a candle.
la ballena	whale	binder	Según una revista de turismo, el invierno es la mejor estación para salir al mar en lancha y ver una ballena.	According to the tourist magazine, winter is the best season to go out on a boat in the ocean to spot a whale.
el buceador	diver	bull	De niño, Miguel comenzó a interesarse por la fauna marina y siempre aspiró a ser buceador.	As a child, Mike became interested in animals that lived deep in the ocean and always aspired to become a diver.
el chaleco	vest	cherry	El bailarín se estaba vistiendo para la competición cuando alguien derramó su café sobre su chaleco.	The ballroom dancer was getting dressed for the competition this morning when someone accidentally spilled coffee on his vest.
la iglesia	church	eagle	En la fiesta, Eva tuvo que repetir una y otra vez como conoció a su novio en la iglesia.	At the party, Jill had to tell the story over and over again about how her and her boyfriend met at church.
el fantasma	ghost	fan	Julia iba en el autobús y la niebla era tan espesa y oscura que creyó que uno de los árboles era un fantasma.	Last night as Jill was driving, the fog was so thick and dark that she mistook the figure of a tree for a ghost.
la flecha	arrow	flag	Manuel estaba en el bosque cuando encontró un ciervo en el suelo después de ser alcanzado por una flecha.	Manuel was in the woods when he found a doe lying on the ground because it had been hit by an arrow.
la nina	girl	knee	Todos los vecinos se sorprendieron mucho cuando se enteraron de que Marcos había secuestrado a la niña.	The whole neighborhood was surprised when they found out that Mark had kidnapped the girl.
la muñeca	doll	moon	María era una chica muy tranquila, pero se enojó muchísimo cuando Sara llegó y le quitó la muñeca.	Mary was a very quiet girl, but got especially mad when Sally came over one day and stole her doll.
la nube	cloud	newspaper	Sandra no pudo ver el paisaje porque estaban volando sobre una enorme nube.	Sandy couldn't see the landscape because they were flying through a cloud.

<u>Spanish Target</u>	<u>English Translation</u>	<u>English Competitor</u>	<u>Conceptually-Biasing Context Sentence (Spanish)</u>	<u>English Translation</u>
el anillo	ring	onion	Pedro recuerda con mucho cariño aquella vez que llevó a su mujer a la tienda donde ella eligió su anillo.	Tom's fondest memory was when he took his wife to the store where she picked out the perfect ring.
la oreja	ear	orange	Ayer, Raúl fue a la barbería a cortarse el pelo, y el barbero sin querer le hizo un corte en la oreja.	Yesterday, Bill was sitting silently in the chair, getting his hair cut, when the barber accidentally nicked his ear.
las hormigas	ants	ornaments	Después de las vacaciones en las Bahamas, Jaime descubrió que su casa estaba infestada de hormigas.	After a vacation in the bahamas, ethan discovered that his house was infested with ants.
el sobre	envelope	soap	Ana estaba muy ansiosa por ver la foto del chico con el que se carteaba cuando abría el sobre.	Anne was anxious to see a photo of her penpal as she opened the envelope.

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