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The role of competing meanings in homograph meaning resolution

by

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Dedication

Graduate school and this thesis have taken a great deal of time and effort on my part, but two other people made essential contributions to the thesis and to my graduate education.

I thank Pete Dixon for his unfailing support and encouragement on many levels over all of the years I have known him.

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I dedicate this thesis to the all of the trees unwillingly turned into the reams of paper that I have used as a graduate student! My daughter and I plan to plant ample replacements.

Abstract

A large body of research on homographs (words with more than one meaning) supports a model of meaning resolution for words that incorporates activation of multiple meanings and selection of a contextually-appropriate meaning. Degree of meaning activation is sensitive to both relative frequency of the meanings and available context. Although context strength has been argued to be a critical determinant of meaning activation levels, most research on context strength has focussed on degree of support for appropriate meanings; little attention has been given to the role of alternate meanings. The hypothesis that the activation level of inappropriate meanings influences activation of appropriate meanings was investigated in the research presented below, using a task which demanded semantic processing. Subjects judged whether target words were related to preceding sentences which contained homographs. All sentence contexts were unambiguously biased toward a single interpretation of the homograph. However, some sentence contexts contained only information consistent with the contextually-appropriate meaning; facilitation of the contextually-appropriate meaning was observed in these contexts. Other contexts were also unambiguously biased but contained a subject noun more commonly associated with the contextually-inappropriate meaning; the inclusion of such information caused interference in the resolution of the contextually-appropriate meaning. While contextual bias influenced meaning activation levels, inhibition between meanings themselves was also shown to be a source of interference. I argue that a critical component of homograph meaning resolution is between-meaning inhibition. Implications for models of ambiguity processing and language comprehension are discussed.

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Introduction

We use language to communicate meaning, and one of the most significant challenges to language comprehension is meaning indeterminacy or ambiguity, which exists at every definable level of linguistic communication. Literary works often have a "surface" and a "deep" interpretation at the level of the discourse as a whole. Pragmatic ambiguity occurs in idiomatic expressions like *He kicked the bucket* which have both a literal and an idiomatic interpretation. In the case of syntactic ambiguity an utterance has two or more possible meanings due to ambiguity in assignment of grammatical roles: *The spy saw the cop with the binoculars* has two interpretations, depending on whether *with the binoculars* modifies *spy* or *cop*. Phonological ambiguity is common in English, for example in the form of homophony (e.g., bear/bare, sweet/suite).

A sentence such as *The men stood beside the pitcher* also permits multiple interpretations but in this case the ambiguity is at the semantic level. The ambiguity occurs because *pitcher* is a homograph (it has at least two meanings) and both of its meanings result in plausible interpretations of the sentence. Homographs (e.g., *pitcher, crane, board*) are an important source of stimuli for the study of meaning resolution because their meanings do not vary on any of the characteristics identified in the word recognition literature as critical to lexical processing. That is, homograph meanings share orthography, phonology (except in the case of rare heterophonic homographs like *wind* and *lead* whose meanings have different pronunciations), word frequency, word length, number of syllables, etc.; only semantic information varies. Furthermore, this control over lexical factors does not come at the cost of a severely limited or otherwise unusual stimulus set. Homographs are prevalent in the English language and in fact constitute a considerable proportion of high-frequency words (Britton, 1978). Semantic ambiguity resulting from the presence of a homograph thus provides a relatively noise-free environment in which to study semantic processes commonly evoked at the word level.

The research reported below was a study of semantic processing for homographs. The goal was to further explicate models of how word meanings are resolved in the face of widespread ambiguity; ultimately, the data are intended to contribute to the development of models of language comprehension. To this end, my primary concern was with fundamental processes of cognition: the activation and inhibition of mental representations. Specifically, I looked at activation and inhibition of word meanings during reading for comprehension. These processes were studied in the context of semantic ambiguity, though it is assumed that the processes are applicable to word meaning resolution in general. That is, most (if not all) English words have multiple senses (see Anderson & Nagy, 1991) and thus the processes of meaning resolution can be assumed to be widely carried out.

I assume the existence of a lexicon of known words which can be accessed by orthographic or phonological input (see Besner, Twilley, McCann, & Seergobin, 1990; Henderson, 1982; Just & Carpenter, 1987; Seidenberg, 1985 for discussions of the lexicon; see Seidenberg & McClelland, 1989 for a model of word processing which does not rely upon a lexicon). In the standard approach (e.g., Morton, 1969), a spoken or written word activates a word detector of some sort, hereinafter referred to as a *lexical representation*, which leads to the activation of word-level knowledge (semantic, syntactic, etc.) in a process termed *lexical access*. Lexical access is followed by *post-access* processes that include "selection, elaboration and integration of lexical information for the purpose of comprehending a text or utterance" (Seidenberg, 1985, p. 203).

Early views of semantic representation claimed that the meaning or meanings accessed for a word were invariant across different contexts (e.g., Armstrong, Gleitman, & Gleitman, 1983; Smith, Shoben, & Rips, 1974). Contrary to this viewpoint, data from the *semantic flexibility* literature demonstrate that the same semantic information is not activated every time a word is encountered. Rather, the meanings ultimately assigned to words vary according to information available at the time the words are being read or heard (e.g., Barclay, Bransford, Franks, McCarrell, & Nitsch, 1974; Barsalou, 1982; Merrill, Sperber, & MacCauley, 1981). For example, Barclay et al. (1974) had subjects complete a cued-recall task for nouns appearing in sentence contexts. Given the cue *something heavy*, recall of *piano* was better following the context sentence *The man lifted the piano* than following *The man tuned the piano*, indicating that different semantic information was activated for *piano* in each of the context sentences.

Data such as these are commonly explained with reference to subcomponents of meaning called *semantic features* (e.g., the concept "apple" consists of features like "red", "edible", "grows on trees", etc.). In *feature theories* of meaning (e.g., Rosch, 1975; Medin & Schaffer, 1978), word meanings consist of a collection of semantic features and meanings vary with context because contexts are related to different meaning features. In some theories, not all features are sensitive to context. Rather, there are context-independent features which are instantiated every time a meaning is accessed and context-dependent features which are instantiated only when consistent with context; this amounts to a claim that words have core meanings and contextual or peripheral meanings (e.g., Barsalou, 1982; Johnson-Laird, 1987). In support of this contention, Barsalou (1982) demonstrated that property-verification time for nouns was unaffected by context for some properties (e.g., the verification of *round* as a property of *basketball* was not affected by the context surrounding *basketball*) while property-verification was faster in relevant contexts for other properties (e.g., the verification of *floats* as a property of *basketball* was faster in a context which had a basketball being used as a life preserver than in one which did not). Other feature theories agree that meanings consist of a collection of features, but they claim that all features are context-dependent to at least some degree (e.g, Paul, Kellas, Martin, & Clark, 1992; Kellas, Paul, Martin, & Simpson, 1991).

While there is widespread theoretical support for the existence of meaning features, there are many reasons to doubt that word meanings can be satisfactorily described by features alone (see Anderson & Nagy, 1991 for a detailed account. Most notably, the idea of a universal set of features which can be used for all meanings is untenable (see Aitchison, 1994; Just & Carpenter, 1987; Murphy & Medin, 1985)). Murphy (1991; Murphy & Medin, 1985) has argued extensively for a model of meaning representation in which meaning consists of features and theories of the world which tie them together. Theories determine what features are central to a meaning and which are peripheral. In Anderson and Nagy's (1991) *family-resemblance model* of word meanings, word meanings come from accumulation of episodic traces of exposures to words, and features serve as *lexical organizers:* Over time, language users come to recognize the semantic relationships among words and they use these relationships (features) to organize their individual experiences with words. (See also Balota, Ferraro, & Connor, 1991 and Masson & Freedman, 1990 for similar arguments about meaning representation). Common to these approaches is the idea that there is more to word meaning than semantic features. In the model of semantic processing I describe below, I assume that a word meaning consists of a representation of the overall meaning (whether this results from a theory or a collection of episodic traces is left unspecified) as well as representations of features; I assume that features vary in both their frequency of association with the meaning and their congruence with a given context. This model of semantic processing requires local representation of meaning. In local representation schemes (e.g., Cottrell, 1989; Waltz & Pollack, 1985) word meanings are represented by concepts, each of which can be associated with meaning features, whereas in distributed representations a word's meaning is simply a collection of semantic features (e.g., McClelland & Kawamoto, 1986; Kawamoto, 1988, 1993). Homographs are usually assumed to have separate concepts and features for each distinct meaning (e.g., Cottrell, 1989; Forster & Bednall, 1976; Henderson, 1982).

One of the most common instantiations of semantic knowledge is that of a network of nodes (often called a semantic network). Each node has a resting activation level, and the nodes are connected to one another by relational pathways which are weighted to indicate strength of association. Activation of a semantic representation consists of an increase in the activation of a node in the semantic network (or nodes, in a distributed representation scheme), and activation spreads across the weighted pathways to related nodes resulting in effects such as semantic priming. Examples of such an approach include Balota, 1994, Collins and Loftus, 1975, Kawamoto, 1988, 1993, MacDonald, Pearlmutter, and Seidenberg, 1994, Posner and Snyder, 1975, Seidenberg and McClelland, 1989; Waltz and Pollack, 1985 (but see McKoon & Ratcliff, 1992 for an alternative to the semantic net notion).

While spreading activation models of semantic processing have been immensely successful, their continued success has resulted from evolution away from original conceptions in which processing consisted solely of automatic spread of activation among related concepts. Most current models are *dual-process* models in which automatic spread of activation is accompanied by attentional processing (see Houghton & Tipper, 1994; Posner & Snyder, 1975; Rafal & Henik, 1994; Simpson & Kang, 1994). In standard priming accounts (e.g., Posner & Snyder, 1975) resources are directed toward attended information and unattended information decays. In negative priming accounts (e.g, Neill, 1977; Tipper, 1985; Houghton & Tipper, 1994) the allocation of resources to attended information is accompanied by active inhibition of competing information. Typical evidence supporting negative priming consists of an activation level for competing (to-be-inhibited) information which is lower than that of irrelevant (to-be-ignored) information. Such an effect has been found with a number of paradigms and tasks (see Houghton & Tipper, 1994 for a review). Evidence for negative priming has resulted in the implementation of inhibitory links between competing nodes in spreading activation models, in addition to facilitatory links between related nodes.

The basic model of semantic processing and representation which underlies my theorizing about meaning resolution for homographs is as follows (see Figure 1). The lexical representation for a homograph increases in activation when the homograph is perceived (although both orthographic and phonological representations of the input may be activated, as shown in Figure 1, the lexical representation referred to here is the orthograpic one, because written rather than spoken text is being studied). The lexical representation activates semantic representations (concept nodes) for each of the homograph's meanings and for strong associates of the homograph, and activation spreads to meaning features associated with each meaning, as well as to associated concepts. All of the connections are weighted by experience; thus semantic representations will be increased in activation an amount proportional to their familiarity (indexed by relative meaning frequency, as per norms such as those of Twilley, Dixon, Taylor, & Clark, 1994). Similarly, meaning features will increase in activation in proportion to their frequency of association with the meaning. So, for example, if the word *board* is perceived in isolation, the concepts "board as a piece of wood" and "board as a committee" will both become active (as well as other meanings, such as "boarding a ship" and "room and board"), with the "wood" meaning being considerably more active than the "committee" meaning (relative meaning frequencies .70 and .07, respectively, Twilley et al., 1994). The "wood" meaning will increase activation of its features, like "inanimate" and "can be sawed", in proportion to their frequency of association with the meaning. Similarly, features like "human" or "makes decisions" will be activated by the "committee" meaning. Presumably, the "wood" meaning will increase the activation of its features to a greater degree than the "committee" meaning because of the higher activation level of the "wood" meaning. Concepts appearing in context follow similar principles of activation. For example, if the word *carpenter* precedes *board* then it would be expected that any concepts and features that are related to the semantic representations of *carpenter* as well as *board* (e.g, the concepts "to saw", "wood", "construction", etc.) would boost activation of *board* before it was perceived, making the "wood" meaning of *board* even more active (hence semantic priming; see Figure 2). More complex contexts than single words would involve more than semantic priming. For example, for sentence contexts, semantic priming would be accompanied by the continuing development of a sentence-level representation in working memory, incorporating information about grammatical categories and thematic roles, for example, to develop a representation of the meaning of the sentence as a whole. Discourse-level biases and processes such as inference-making would be expected to play roles as context complexity increases.

Spread of inhibition between competing concepts is assumed, but the extent and specifics of such inhibition for homographs are largely unknown. In spite of the abundance of evidence for the presence of inhibitory connections between competing concepts in other paradigms, little evidence for inhibition in the processing of homograph meanings has been found (see review below). The majority of discussions of homograph meaning inhibition have assumed (implicitly or explicitly) that inhibition is from contextual concepts to inappropriate meanings. One of the primary foci of my research was to search for evidence of *between-meaning* inhibition in homograph meaning resolution. Possible models of inhibition will be discussed following presentation of this evidence. Below I review semantic ambiguity research over the last few decades in order to combine the insights gained from that literature with models of semantic processing.

Early models of semantic ambiguity processing

The semantic ambiguity literature grew rapidly in the late 1970's and early 1980's, largely in response to a single issue in cognitive science: What is the influence of contextual information on perceptual processing during completion of cognitive tasks? (For literature reviews on lexical ambiguity processing see Bubka & Gorfein, 1989; Rayner, Pacht, & Duffy, 1994; Simpson, 1984, 1994; Simpson & Burgess, 1988.) In word recognition, the lexical modularity debate is concerned with whether initial activation of word meanings occurs prior to or in concert with contextual influences. Modularity supporters contend that the lexicon is a module, impermeable to contextual influence and that context effects occur "outside" the lexicon. "Context" generally refers to relationships other than simple lexical associations (e.g., *bread* and *butter*). Lexical associates prime one another in various tasks, but this effect is presumed to involve simple spreading activation between related concepts and does not violate autonomy of the lexicon (Henderson, 1982; Seidenberg, 1985). "True" context effects are the result of more than just spreading activation and involve higher-level processes such as conscious prediction, use of world knowledge, elaboration, and integration. Unlike modularity theorists, supporters of non-modular viewpoints argue that initial activation of word meanings *is* affected by context.

Because the meaning (and only the meaning) of a homograph is manipulated with context changes, semantic ambiguity processing provides critical insight into the interplay between meaning activation and context. The time course of semantic ambiguity processing is of particular relevance in this debate (for discussions, see Neill & Klein, 1989; Prather & Swinney, 1988; Simpson, 1984; Simpson & Burgess, 1988; Swinney, 1991;

Tabossi & Zardon, 1993). Very early or immediate effects of context on activation of homograph meanings (often called selective meaning access) indicate a lack of modularity; support for modularity comes from evidence for context-free (or non-selective) activation.

In *selective access* models initial activation and selection occur in the same stage and are contextually determined. That is, only the contextually-appropriate meaning is activated (e.g., Glucksberg, Kreuz, & Rho, 1986; Schvaneveldt, Meyer, & Becker, 1976). In their classic study, Schvaneveldt et al. primed homograph meanings and then presented test words for lexical decision. They found that lexical decisions to the test words were facilitated when the test words were related to the primed meaning of the homograph, and not facilitated when the test words were related to an unprimed meaning of the homograph. Schvaneveldt et al. claimed that appropriate context resulted in selective activation of a single homograph meaning. Schvaneveldt et al.'s study, as well as some others supporting context-dependency of meaning activation, has been criticized on the grounds that the effects observed may have simply been at the level of lexical association. Strong evidence for context-dependence requires use of words that are not associatively related to the homographs. Seidenberg, Tanenhaus, Leiman, and Bienkowski (1982) found selective activation of contextually appropriate meanings of homographs only when lexical associates of homographs were present in preceding context; they concluded that strong lexical associates were necessary for selective activation to occur. Subsequent studies found evidence for selective activation with short ISI's in the absence of strong lexical associates, however (e.g., Simpson & Krueger, 1991; Tabossi, Colombo, & Job, 1987).

In *ordered access* models, activation of homograph meanings is ordered by meaning frequency (more common meanings are activated before less common meanings) but is not sensitive to context (e.g., Forster & Bednall, 1976; Hogaboam & Perfetti, 1975; Holmes, 1979). Ordered access models are thus selective, but because the basis of the selection is not context but meaning frequency (which is presumed to be internal to the lexicon, like lexical association) ordered access models are modular.

Non-selective *exhaustive access* models have traditionally enjoyed stronger support than selective access models. In classic exhaustive access models of ambiguity processing, a separate access stage is assumed and contextual effects on lexical processing are ascribed to post-access processes (with an implicit assumption that meaning selection follows access). All known meanings of a homograph are automatically activated when a homograph is presented regardless of preceding context (e.g., Conrad, 1974; Seidenberg et al., 1982; Tanenhaus, Leiman, & Seidenberg, 1979; Till, Mross, & Kintsch, 1988). In extreme versions of exhaustive access, even meaning frequency does not affect homograph processing; all meanings are not only activated automatically and in parallel but to equal degrees (Lucas, 1987; Onifer & Swinney, 1981; Swinney, 1979). Support for exhaustive activation came from studies such as Swinney's (1979) finding of facilitation for both contextually appropriate and contextually inappropriate homograph meanings with no delay between hearing the homograph and the appearance of a visual lexical decision target. When a delay between processing of the homographs and making lexical decisions to target words was introduced, facilitation occurred only for contextually appropriate meanings. Swinney (1979) interpreted his data as indicating that initial activation is insensitive to context and is followed by processing which selects the appropriate meaning.

Methodological issues have dominated the modularity debate. Simpson (1994) summarized several possible methodological reasons for the paradoxical support found for both non-selective and selective models. He provided evidence demonstrating that task type (naming, lexical decision or Stroop), position of homograph within sentence context (medial or sentence-final), and type of context presentation (cross-modal or unimodal) were *not* predictive of results in lexical ambiguity studies; support for both non-selective and selective models has been reported under each of the conditions listed above. In recognition of this lack of consensus, models of ambiguity processing that were not strictly modular nor strictly interactive but somewhere between these two extremes began to appear in the literature in the 1980's.

Context-sensitive models of semantic ambiguity processing

Context-sensitive models of ambiguity processing are essentially modified exhaustive access models in that multiple meanings for homographs *can* be activated very early in processing, in parallel, but the speed and/or degree of activation of each meaning is concurrently dependent on contextual bias (as in selective access models), relative meaning frequency, and task demands (Duffy, Morris, & Rayner, 1988; Gorfein & Bubka, 1989; Neill, 1989; Neill, Hilliard, & Cooper, 1988; Rayner & Frazier, 1989; Rayner et al., 1994; Simpson, 1981, 1984, 1994; Simpson & Kellas, 1989; Simpson & Krueger, 1991; Tabossi & Zardon, 1993; Whitney & Clark, 1989). Context-sensitive models are akin to modular models in that activation of multiple meanings occurs; thus a selection process must come into play. However, context-sensitive models are in fact non-modular because initial activation is sensitive to contextual influences.

Facilitation of contextually-appropriate meanings but not contextually-inappropriate ones in short SOA conditions in priming tasks provides evidence of context-dependence of the lexicon; facilitation of contextually-inappropriate as well as contextually-appropriate meanings under these conditions supports modularity of the lexicon. As discussed above, both of these types of findings have been reported and used to support selective and non-selective models, respectively. Importantly, there is a critical trend in the data (consistent though rarely statistically significant; see Simpson, 1984 for discussion) for the contextually inappropriate meaning of a homograph to show *no* facilitation or *less* facilitation than the appropriate meaning with SOA's of 100 ms or less. This has been shown for cross-modal lexical decision (Simpson, 1981, Experiment 2; Swinney, 1979), naming (Seidenberg et al., 1982; Simpson & Krueger, 1991; Tanenhaus et al., 1979), and colour-word naming (Oden & Spira, 1983). The ERP data of van Petten and Kutas (1987, 1988) suggest that even though both appropriate and inappropriate meanings are facilitated early on in a naming task, the onset of this facilitation is delayed slightly for inappropriate meanings. Across various tasks, then, there is evidence that immediately after initial meaning activation, inappropriate meanings are less activated than appropriate meanings.

Context-sensitive models of ambiguity processing correctly predict that certain experimental situations may indeed provide evidence of early activation of contextually-inappropriate meanings but these meanings will generally be activated to a lesser degree or more slowly than contextually-appropriate meanings. Whether this difference in activation is observed will depend on the sensitivity of the experimental situation. Variability across studies in context types and strength, range of meaning frequencies used, tasks, timing, and dependent measures contributes to experimental sensitivity differences. The main tenet of context-sensitive models is that meaning activation is a function of relative meaning frequency and context strength. There is abundant evidence for the influence of these factors.

In virtually all semantic ambiguity tasks the normatively determined relative frequencies of the different homograph meanings have an impact on performance. Naming times for words related to primary homograph meanings are faster than naming times for words related to secondary meanings (e.g., Simpson & Foster, 1986; Simpson & Krueger, 1991). Similarly, lexical decision times are faster for words related to primary meanings than for words related to secondary meanings (e.g., Burgess & Simpson, 1988; Frost & Bentin, 1992; Lucas, 1987; Simpson, 1981; Simpson & Burgess, 1985; Tabossi et al., 1987). Carpenter and Daneman (1981; see also Daneman & Carpenter, 1983) found meaning frequency effects for heterophonic homographs like *wind* and *tears*, whose meanings vary with pronunciation. Subjects were asked to read passages aloud with the end goal of being able to answer comprehension questions. Pronunciation data were used to assess which meaning of the homographs was resolved. Thirty-eight percent of secondary-meaning homographs and 87% of primary-meaning homographs were pronounced correctly when embedded in appropriately biasing contexts, demonstrating a strong effect of meaning frequency. Holmes (1979) found that classifications of sentences' meaningfulness were faster for sentences biased toward primary meanings of homographs than for sentences biased toward secondary meanings. Eye movement monitoring during reading comprehension tasks has shown that gaze durations are shorter for polarized homographs with one strongly dominant meaning than for balanced homographs with a primary and a secondary meaning which are similar in frequency (Duffy et al., 1988; Rayner et al., 1994). Assuming that gaze duration reflects meaning resolution time, this finding demonstrates that homograph meanings are resolved faster if they are more frequent. All of the above data support the contention that meaning frequency has an early and strong role in meaning resolution.

Several experimenters have reported that initial meaning activation varies with context strength as well as with relative meaning frequency (Carpenter & Daneman, 1981; Holmes, 1979; Kellas et al., 1991; Paul et al., 1992; Simpson, 1981; Simpson & Krueger, 1991). For example, Simpson (1981) varied context strength and meaning frequency in a lexical decision task in which sentence-ending homographs were followed by a target word. Sentence contexts were either non-existent (homograph only; e.g., *count* followed by target *number*), weakly biasing (e.g., *The musician kept losing track of the count* followed by target *number*), or strongly biasing (e.g., *My dog wasn't included in the final count*). In the no-context condition, Simpson (1981) found that lexical decisions to target words that were related to the primary meanings of the homographs were facilitated relative to words unrelated to the homographs. Words related to secondary meanings of the homographs were not facilitated. When the homographs were preceded by weakly biased sentence contexts, primary meanings were facilitated regardless of sentence bias but secondary meanings were facilitated only when the sentence was biased toward the secondary meaning. Strongly biased sentences led to facilitation of only the biased meaning (relative to unrelated words), regardless of meaning frequency. Thus Simpson (1981) found frequency ordered activation (in the no-context condition), non-selective activation (for sentences weakly biased toward secondary meanings) and selective activation (for strong sentence contexts and weak sentence contexts biased toward the primary meaning)--all within the same experiment.

In Holmes' (1979) meaningfulness classification task, there was a strong meaning frequency effect on classification times for sentence contexts that contained verbs which were neutral but nouns which were related to a homograph meaning (e.g., *The botanist inspected the plant thoughtfully*). The effect of meaning frequency was rendered marginally reliable by biasing the verbs so that only one meaning of the homograph formed a possible interpretation of the sentence (e.g., *The electrician was asked to install the bulbs*). Meaning frequency effects were non-significant in the strongest contexts, which contained biased nouns as well as a synonym of the homograph in a previous sentence (e.g., *The manager forced the robber to run out of the building. The robber was chased from the bank*).

Interacting effects of context strength and meaning frequency demonstrate that context dependence is a matter of degree (not all-or-none as the modularity debate tended to constrain it to be). Activation levels of meanings and their associated features vary along a continuum and are determined jointly by contextual influence and relative frequency. When context is absent relative frequency alone determines the (resting) level of activation for a meaning. Strong contexts will result in relatively large boosts in activation of the appropriate meaning, overshadowing meaning frequency. With weak contexts both context strength and relative frequency effects will be evident in the activation level of a meaning. Thus context-sensitive models effectively explain conflicting non-selective/selective activation results. These models remain incomplete in some critical areas, however.

Issues for model development

Definition of context strength

In spite of the clear role that context strength plays in meaning resolution there is a distinct lack of consensus on the issue of what constitutes a strong context. In Simpson's (1981) landmark study, context strength was based on the experimenter's intuitions and validated by judges' ratings on a Likert-type scale. Simpson and Krueger (1991) used Simpson's (1981) stimuli but they eliminated lexical associates (and still found effects of context strength). Carpenter and Daneman (1981) also used judges' ratings, with a somewhat more systematic scale. Weak contexts were neutral or contained a single semantic associate. Strong contexts contained more than one semantic associate, perhaps a cliche or stereotypic phrase involving the homograph, and the homograph was "strongly implied by the scene" (Carpenter & Daneman, 1981, p. 143). While an implicit assumption was made that strong contexts had to contain both lexical and pragmatic bias toward a meaning, these criteria were arbitrary and not empirically supported.

Rayner et al. (1994) avoided subjective ratings. Homographs were either presented in a paired-associate task and in a subsequent sentence context (repetition condition) or in a sentence context only (no repetition). Fixation times on the homographs in the sentence contexts were shorter in the repetition condition, indicating facilitation due to repetition. Simpson and Kang (1994) found no facilitatory effects of meaning repetition in a naming task with word primes. In a subsequent sentence verification task there was a facilitatory effect of meaning repetition across trials, however. The Rayner et al. (1994) data and the Simpson and Kang (1994) data indicate that previous recent activation of a meaning renders a meaning more active for some period of time, at least in tasks which require more than minimal semantic processing. This type of context effect is a short-term analogue to longer-term meaning frequency effects.

Tabossi et al. (1987) showed that *safe* will prime one meaning of *port* and *red* will prime the other, in spite of the fact that neither *red* nor *safe* are strong lexical associates of *port*. In Tabossi's view (1988, 1989, 1991; Tabossi et al., 1987) *feature priming* occurs when a context successfully activates characteristic features of a homograph meaning. Thus *safe* primes the "harbour" meaning of *port* and *red* primes the "wine" meaning because *safe* and *red* are characteristic features of the respective meanings of *port* (Tabossi et al., 1987). Tabossi's feature-priming approach is promising in that it uses a single concept (priming of characteristic features) to operationalize strength of context. It can be used to explain effects of context strength found in other paradigms by other researchers. Synonyms as well as pragmatically related concepts share key features and thus prime each other. If activation of meaning features persists for some period of time then meaning repetition effects would follow. In the general model of semantic processing I outlined in the Introduction, Tabossi's feature priming amounts to spread of activation between homograph meaning features and related concepts.

Paul et al. (1992) argued for modification of the feature priming approach, demonstrating that selective activation of a meaning occurs only when features of target words are related to contextually-activated features of homograph meanings. In this case, context strength is "a function of the degree of overlap between features activated by context and the features represented by upcoming words" (Kellas et al., 1991, p. 53). This amounts to spread of activation between features which are shared by homographs and context words (rather than between features and contextual concepts, as in Tabossi's account).

The feature priming account is consistent with data from other labs. Dopkins, Morris, and Rayner (1992) found that reading times for homographs were shorter when preceded by unambiguous contexts consistent with a single meaning (e.g., *Having been opened and disassembled, the speaker...)* than when preceded by ambiguous contexts that were consistent with more than one meaning (e.g., *Inaudible as a result of the static, the speaker...).* Dopkins et al. thus showed that contexts which were restricted to a single interpretation were more successful at evoking a given meaning than contexts which allowed alternate interpretations. Holmes (1979) also found that the efficacy of the context was increased by allowing a single interpretation only. Holmes' (1979) data and Dopkins et al.'s (1992) data demonstrate that effective contexts for homographs are those that narrow processing to a single alternative.

Under Tabossi's feature priming account, limiting processing to a single alternative is accomplished by priming salient features of the intended homograph meanings. However, the feature priming account is not the only interpretation of Dopkins et al. (1992) and Holmes (1979). The stimuli used by Holmes (1979) and Dopkins et al. (1992) as well as the strong (but not weak) contexts from Simpson (1981) have in common the exclusion of alternative interpretations *as well as* priming of intended interpretations. It is thus quite plausible that effective contexts must eliminate alternative meanings as well as evoke intended meanings.

This possibility was addressed by Reder (1983). Reder created unambiguous sentences biased toward a single meaning; the sentences varied in support for the meaning. In *positive prime* sentences some of the context preceding the homograph (in the following examples, the relative clause) was related to the intended meaning (e.g., *The groom, who replaced his tobacco pouch, lit his pipe.*). In *negative prime* sentences some of the context preceding the homograph was related to an unintended meaning (e.g., *The groom, who repaired the sewer, lit his pipe.*). In control sentences the priming information from the other conditions was replaced by unrelated information (e.g., *The groom, who took the message, lit his pipe.*). When subjects were asked to generate continuations for the sentences, they were faster to generate continuations for positively primed sentences than controls, indicating that facilitation of the intended homograph meaning occurred. The response times for the negative priming condition were not slower than those in the control condition but subjects made many more errors in the negative priming condition than in the control condition, indicating that the homograph was misinterpreted more often in the negative priming condition. The results suggest that positive evidence for a meaning is indeed effective in evoking that meaning but that negative evidence for a meaning causes interference in resolution of that meaning.

Reder (1983) showed that context may fail to lead to meaning resolution due to interference from information consistent with another meaning in spite of strong support for the intended meaning. These data, along with that of Dopkins et al. (1992) and Holmes (1979), show that there is a role for information related to alternative interpretations, in addition to the well-established role of informaton related to intended interpretations. Associative priming approaches which describe context strength in terms of support for intended interpretations (such as Tabossi's feature priming account) are incomplete. In particular, models must include some sort of mechanism by which competing interpretations interfere with one another. An obvious candidate is inhibition between competing interpretations. Such inhibitory effects are considered in more detail below.

Meaning selection

Meaning selection processes are a neglected area of ambiguity research. Although Conrad (1974), in one of the pioneering papers in the field, spoke of the need for hypotheses of meaning selection as well as meaning access, interest in the modularity debate overshadowed interest in meaning selection processes for many years. Researchers were primarily interested in only the first one or two hundred milliseconds of processing (presumed to consist of initial activation uncontaminated by selection or integration processes) and consequently most research neglected meaning selection processes. The renewed interest in the range of parameters affecting meaning resolution in its entirety, sparked by the context-sensitive approach, extends to understanding how a meaning is selected from the multiple candidates that are generated in all but the strongest contexts.

The continued activation of contextually-appropriate homograph meanings past the point of initial activation (500 ms SOA or more) is undisputed. Contextually-appropriate primary meanings have been shown to be more active than unrelated controls (e.g., Onifer & Swinney, 1981; Simpson & Krueger, 1991) as have contextually-appropriate secondary meanings (e.g., Onifer & Swinney, 1981; Simpson & Krueger, 1991; van Petten & Kutas, 1987).

Contextually-inappropriate meanings, whether primary or secondary, are generally not more active than unrelated controls 500 ms or more after they are presented (Onifer & Swinney, 1981; Simpson & Krueger, 1991; Swinney, 1979; Tanenhaus et al., 1979; van Petten & Kutas, 1987, 1988). These data have intuitive appeal: Comprehension can be said to be achieved when inappropriate or uncommon interpretations are no longer activated to a significant degree and thus processing settles on the correct interpretation. The crucial question is how this resolution, with contextually-appropriate meanings being facilitated and inappropriate meanings no longer remaining active, comes about.

Two major types of models have been proposed: Those that contend that resolution is a matter of activating one homograph meaning and ignoring others, and those that contend that both activation of the to-be-selected meaning and *inhibition* of others are involved. Activation-only models of resolution claim that appropriate meanings are kept active from input from context and inappropriate meanings simply decay with the passage of time due to lack of support from context (e.g., Anderson, 1983; Carpenter & Daneman, 1981; Simpson & Burgess, 1985; Yates, 1978; see Simpson, 1984 and Simpson & Kang, 1994 for arguments that such a model has been assumed by most semantic ambiguity researchers). Such models are akin to standard dual-process models of priming (e.g., Posner & Snyder, 1975) in which spread of activation is accompanied by allocation of attention to appropriate meanings and withdrawal of attention from inappropriate meanings. This account is supported by data that show that after a brief delay, words related to inappropriate meanings are no more active than words unrelated to the inappropriate meanings, though words related to appropriate meanings are more active than unrelated words (Simpson & Burgess, 1985; Simpson & Krueger, 1991).

The work of Rayner and colleagues is consistent with a decay account of meaning resolution. In their *reordered access model* (Duffy et al., 1988; Rayner et al., 1994) they argued that after multiple meanings are activated (with the speed of activation varying with context and meaning frequency) there is an attempt to integrate each meaning with context. Successful integration of the contextually-appropriate meaning leads to a boost in activation of that meaning but not the inappropriate meaning. Thus "selection is simply integration of an input with context" (Rayner & Frazier, 1989, p. 786).

While decay of meaning activation may in fact be part of the reason for the decline in activation of inappropriate meanings with increasing homograph-target SOA, some argue that decay processes would be too slow-acting to explain the fact that inappropriate meanings are often inactive within 200 ms of target presentation (Onifer & Swinney, 1981; Tanenhaus et al., 1979). Furthermore, proponents of negative priming-type approaches argue that there is abundant evidence for the existence of inhibitory connections between competing concepts. For example, Gernsbacher and Faust (1991a, b; Gernsbacher, Varner, & Faust, 1990) claimed that multiple meanings are activated and that context serves to activate appropriate meanings and inhibit inappropriate meanings.

As argued by Simpson and Kang (1994) simple withdrawal of attention would leave inappropriate meanings and unrelated words in the same (inactive) state, whereas only inhibition of inappropriate meanings could make them less active than irrelevant unrelated words. Simpson and Kang looked for such inhibition effects using a homograph repetition procedure in which homographs served as primes for target words in a naming task (see also Simpson & Kellas, 1989). In the Same condition, homographs primed words related to a given meaning on two trials (e.g., *bank* primed *save* on one trial and *money* on a subsequent trial). In the Different condition, homographs primed words related to different meanings on two different trials (e.g., *bank* primed *stream* on one trial and *money* on a subsequent trial). In the Unrelated condition, the homographs from Same conditions were replaced by unrelated words (e.g., *calf* preceded *save* on one trial and *money* on another trial); this condition served as a baseline for the activation level of the targets in the absence of semantic priming. Naming times to targets following repeated homographs in the Different condition were significantly slower than naming times to the same targets following unrelated words: There was inhibition of homograph meanings to an activation level below that of unrelated words. Importantly, inhibition of inappropriate meanings occurred *only* when a competing meaning was primed on a previous trial and not when a homograph was paired with unrelated information on a previous trial (Simpson & Kang, 1994, Experiment 2). Furthermore, the inhibition effect was replicated with sentence contexts in a sentence-verification task (Simpson & Kang, 1994, Experiment 3). Simpson and Kang argued for an active inhibition process. They claimed that context draws attention to one homograph meaning, activating that meaning and actively inhibiting others, as in negative priming. When the homograph is presented on a subsequent trial, responding to another meaning is difficult due to the inhibition of the meaning.

These data make it clear that competing homograph meanings are inhibited under at least some circumstances. Of interest is how such inhbition comes about. All of the above accounts of meaning resolution, including that of Simpson and Kang (1994) assumed a contextual basis for meaning selection, with context directing attentional allocation. However, there is another plausible account of their data. Perhaps inhibition which is not contextually-directed but is at the level of the meanings themselves contributed to the inhibition of the unprimed meaning of the homograph in Simpson and Kang's (1994) data (and to homograph meaning resolution in general). That is, perhaps inhibition of contextually-inappropriate meanings is at least partly from the representation of the other meaning as well as from the representations of contextual information. Thus perhaps when *bank* is followed by *stream* the "side of a river" meaning of *bank* inhibits the "financial institution" meaning of bank.

The distinction between these two possibilities has important implications for model development. If inhibition is solely from context, then inhibitory links need only exist between contextual concepts and word meanings. However, if inhibition is at least in part from between-meaning competition, then meaning resolution models must incorporate inhibitory links between competing homograph meanings themselves. The theoretical question is whether the activation of one meaning is a function of the activation of another (i.e., meaning activation levels are co-dependent and mutually inhibitory) or meaning inhibition is a result of contextual influence (i.e., meanings are independent and inhibition is from contextual concepts only).

The strong view of meaning dependence is that meanings are completely co-dependent: As the contextually-appropriate meaning increases in activation it inhibits the inappropriate meaning in proportion to its increase, thus never allowing full activation of both meanings. However, the decline in activation of contextually-inappropriate homograph meanings with time is not typically accompanied by an increase in activation of contextually-appropriate meanings (e.g., Onifer & Swinney, 1981; Seidenberg et al., 1982; Swinney, 1979) as would be expected if activation levels of homograph meanings were completely dependent on one another. Furthermore, if meanings were completely co-dependent, they could never be fully active simultaneously (some mathematical and computational models of ambiguity processing allow only one homograph meaning to become fully active; e.g., Kawamoto, 1988, 1993; Waltz & Pollack, 1985). Although it is hard to evaluate what a "fully active" meaning is behaviourally, we can ask if multiple meanings of homographs can be strongly active simultaneously. The abundant support for activation of multiple homograph meanings in weak contexts (see above) indicates that this is indeed the case, though the activation of multiple meanings is generally quite short-lived. Perhaps a purer measure of the co-occurrence of two meanings can be found in the comparison of primary and secondary meaning activation levels in the absence of context. The typical pattern is that of unvarying facilitation of primary homograph meanings relative to unrelated controls at all SOA's and an inverted-U pattern for secondary meanings, with no facilitation at very short SOA's or at long SOA's but equal facilitation to primary meanings at SOA's of about 300 ms (naming task, Simpson & Burgess, 1985; Simpson & Krueger, 1991). Thus although the pattern of activation varies for primary and secondary meanings, it is certainly the case the primary and secondary meanings can be equally facilitated simultaneously (at SOA's of about 300 ms). Because it is impossible to evaluate whether meanings have been "fully activated" these data cannot support complete meaning independence but they do make it clear that homograph meaning activation levels are at not completely co-dependent; they are to some extent independent.

There are some models with completely independent meanings. In Twilley and Dixon's (1996) mathematical model of homograph meaning processing, meaning activation is a function of the resting level of a meaning (determined by meaning frequency) and independent input from perceptual processes and contextual processes. Activation of a meaning is a function of the sum of perceptual input, contextual input, and resting level. Contextual influences are either positive (facilitatory) or negative (inhibitory). Meanings are fully independent in that the activation level of one meaning does not influence the activation level of another; the only differential influence on meanings comes from context. Twilley and Dixon used this simple model to successfully simulate many of the important findings in the literature, including interactions between context strength and meaning frequency, and early effects of context. Gernsbacher and Faust (1991a, b) and Rayner et al. (1994) also proposed models with inhibitory mechanisms, also from context only.

It seems clear that homograph meanings are not completely co-dependent: At least part of homograph meaning inhibition is contextually-driven, as claimed by Simpson and Kang (1994) and Gernsbacher and Faust (1991a, b) and others. However, there remains the possibility that homograph meanings are inhibited by competing meanings as well as context. The empirical challenge is to define the circumstances under which inhibition of meanings from context and from alternate meanings operates. Simpson and Kang's (1994) data do not allow discrimination between between-meaning inhibition and context-meaning inhibition. Furthermore, although Simpson and Kang (1994) found inhibition only when homographs were repeated with different meanings instantiated on each appearance, it is possible that homograph meaning inhibition is a more general phenomenon, occurring routinely in the course of meaning resolution regardless of whether alternate meanings are specifically primed.

In the research reported below I attempted to find evidence for inhibition from competing meanings in the absence of homograph repetition in order to determine whether between-meaning inhibition is not in fact limited to situations in which homographs have been processed to the point of a response on a previous trial. Furthermore, I looked for evidence of between-meaning inhibition that could not be attributed to context.

Individual differences

Following work by Gernsbacher and her colleagues and Just and Carpenter and their colleagues, I investigated the role of individual differences in homograph meaning processing. The study of between-reader differences in ambiguity processing is predicated on the assumption that word meaning is not solely a text characteristic; meaning is resolved through reader-text interaction (Daneman, 1988).

There are some data on the relationship between working memory and ambiguity processing which make it clear that readers with large working memories maintain more than one homograph meaning when it is beneficial to do so (i.e., when preceding context is not biasing toward one meaning of a homograph or another). Daneman and Carpenter (1983) found that readers with low scores in the Reading Span task (Daneman & Carpenter, 1980) were less likely to be able to resolve misinterpretations of semantic ambiguities. That is, after reading aloud an unbiased sentence containing a heterophonic homograph (e.g., *There were some who were expert at bass...*) low-span subjects who pronounced the homograph incorrectly were less likely to be able to reinterpret the sentence correctly than high-span subjects. Daneman and Carpenter claimed that high-span readers are better able to maintain activation of multiple word meanings and are therefore better able to resolve interpretation problems that may arise from multiple-meaning words. Miyake et al. (1994) showed that low-span readers had long gaze durations on regions that disambiguated sentences toward secondary homograph meanings, indicating that the low-span readers had only the primary meaning available. High-span readers had little difficulty with the disambiguating regions in secondary-biased sentences, presumably because they had both the primary and secondary interpretations readily available in working memory.

Gernsbacher et al. (1990; see also Gernsbacher and Faust, 1991a) studied individual differences in ambiguity processing using the *meaning-fit task* which required subjects to read a sentence followed by a target word. Subjects judged whether the target word was related to the meaning of the sentence. The sentences contained homographs, and response times to the target words were used to assess activation of homograph meanings. Interference occurred when there were longer reaction times to sentences biased toward a meaning of a homograph unrelated to the target (e.g., *He dug with the spade* followed by *ACE*) than to sentences ending in a non-ambiguous synonym of the homograph (e.g., *He dug with the shovel* followed by *ACE*). Gernsbacher et al. (1990) found interference from contextually-inappropriate homograph meanings at both short (100 msec) and long (850 msec) sentence-target SOA's for poor comprehenders, while good comprehenders showed interference at short delays but not at long delays. Gernsbacher et al. (1990) concluded that inappropriate meanings are inhibited after initial activation, and that poor readers were unable to disregard the irrelevant meaning of the homograph (e.g., the "card" meaning of *spade*) after reading the biased sentence .

On the surface it appears that Just and Carpenter 's conclusions contradict those of Gernsbacher. Just and Carpenter claimed that good readers maintained multiple interpretations of information they were trying to comprehend, while Gernsbacher claimed that good readers quickly disregarded irrelevant information. These two viewpoints are easily resolved, however. Good readers maximize the likelihood of achieving comprehension. When context is ambiguous good readers do not resolve the meaning of a homograph but maintain alternate interpretations; when context is biased and supportive of a single interpretation, good readers inhibit inappropriate meanings.

In spite of their interesting findings, the above studies are somewhat compromised by choice of individual-difference measure. The Reading Span task used by Daneman and Carpenter (1980, 1983) is by far the most popular index of working memory ability in psycholinguistic literature; however there are problems with this measure. The moderate correlations observed between Reading Span and comprehension measures ($r = .46$ in Baddeley, Logie, Nimmo-Smith & Brereton, 1985; $r = .59$ in Daneman & Carpenter, 1980; $r = .58$ in Daneman & Carpenter, 1983; $r = .39$ in Dixon, LeFevre, & Twilley, 1988) indicate that the relationship between reading ability and Reading Span is not strong. The lack of a strong relationship could indicate a reliability problem. Furthermore and more importantly, uunpublished research conducted by the author showed that between-subject variability on the Reading Span task is quite limited in populations of university students (only 11 out of 116 subjects had Reading Span scores other than 3 or 4, with a possible range from 0 to 6) resulting in unreliable and small effects of Reading Span on a variety of reading tasks.

While reading comprehension tasks (such as that used by Gernsbacher and colleagues) would seem to be an ideal medium for looking at individual variability on component reading skills, there are problems with extant tests of comprehension skills for university-level readers. Gernsbacher and Varner's (1988) test, while requiring written responses to a variety of questions in different modalities, has not been normed on a large population and thus its reliability is unknown. The Nelson-Denny Comprehension test (Brown, Bennett, & Hanna, 1981), though having established reliability, is in multiple-choice format and allows unlimited re-reading to search for answers. Facility at such question-answering is likely to be substantially different from what is generally meant by natural reading comprehension.

The logical place to look for an appropriate individual difference measure for word meaning resolution would seem to be at the level of word knowledge. Daneman (1991) reviewed the literature on the role of word knowledge in individual differences in reading. She noted that vocabulary was the single best predictor of reading comprehension skill. This relationship appears to be consistently strong across a variety of age groups and skill levels.

There is support for the "learning from context hypothesis" of Sternberg and Powell (1983) which states that vocabulary and comprehension are both measures of ability to acquire knowledge from context during reading and listening: Whereas teaching children the meanings of words that will appear in subsequent texts does not improve comprehension of those texts (Tuinman & Brady, 1974, cited in Daneman, 1991) training readers to infer plausible word meanings while reading texts does improve comprehension (Beck, Perfetti, & McKeown, 1982). The individual differences research summarized above suggests that this ability to use context to resolve word meanings is based on context-appropriate resolution of meanings. If the context provides information biased toward a word meaning other meanings will be inhibited in favour of the contextually-appropriate meaning. Thus, while high-vocabulary readers would be expected to show smaller effects of homograph meaning frequency than low-vocabulary readers (they know more word meanings by definition and thus are more familiar with low-frequency meanings than low-vocabulary readers) high-vocabulary readers should also be more likely than low-vocabulary readers to resolve homograph meanings in biased contexts. When meanings are in competition with one another in contexts biased toward one meaning (as in *The chairman sawed the board*) the inability of low-vocabulary readers to inhibit the competing inappropriate meaning is predicted to result in especially high levels of activation of the inappropriate meaning. This prediction was tested in the experiments reported below.

Dependent measure of meaning activation

The importance of choice of individual difference measure has a corollary in the choice of dependent measure. A large proportion of semantic ambiguity research has used priming tasks (lexical decision, naming, Stroop) to assess meaning activation. Although useful for minimizing "contamination" by processes subsequent to initial activation for purposes of addressing the modularity issue, it is my contention that such tasks ignore the central task of language comprehension: meaning assignment. By design, semantic processing is minimal in priming tasks. In order to make meaningful contributions to a model of meaning resolution, it is essential that we look at data collected during performance of tasks that actually require resolution of meaning for words. All three experiments reported below employed the meaning-fit task (adapted from Gernsbacher et al. 1990) to assess meaning resolution. This task is ideally suited to study meaning resolution because it requires activation, selection, and integration of meaning for successful completion. Furthermore, the meaning-fit task allows comparison of activation levels of different meanings by varying the relatedness of homographs and target words. Heterophone pronunciation tasks such as that used by Carpenter and Daneman (1981) and Daneman and Carpenter (1983) not only use rare stimuli but provide information only about which meaning is finally selected (i.e., which meaning is pronounced) rather than the *relative* level of activation of meanings. The popular technique of timing eye movements during comprehension of semantically ambiguous sentences (Carpenter & Daneman, 1981; Daneman & Carpenter, 1983; Dopkins et al., 1992; Duffy et al., 1988; Rayner & Duffy, 1986; Rayner & Frazier, 1989; Rayner & Morris, 1991; Rayner et al., 1994) does not readily provide data on the relative activation level of different meanings because reading time data are only a measure of overall processing difficulty. The meaning-fit task on the other hand allows assessment of the activation of both primary and secondary meanings.

An incomplete model of meaning resolution

The semantic ambiguity literature reviewed above can be accommodated within the model of semantic processing presented in the Introduction. Connections between lexical representations and semantic representations are weighted by familiarity, so that the activation level of homograph meanings in isolation is strongly influenced by relative meaning frequency. Lexical associates and synonyms make strong contexts because of spreading activation among related semantic representations. The success of feature priming indicates that at least some of the spreading activation involves meaning features rather than just concepts. The influence of pragmatic biases (i.e., world knowledge) can be assumed to be due to higher-level context effects involving more than just spread of activation. Repetition priming is successful because decay is not immediate; rather, activation patterns linger for some time. Contexts which constrain interpretation to a single meaning are stronger than those that do not because such contexts not only activate appropriate meanings but likely inhibit inappropriate meanings, through facilitatory connections between related concepts and inhibitory connections between competing concepts. High-vocabulary readers have better knowledge of secondary homograph meanings, resulting in higher activation levels for these items than low-vocabulary readers. High-vocabulary readers also have more and/or stronger inhibitory connections, resulting in greater inhibition of inappropriate homograph meanings.

The most interesting aspect of the above account is in fact what is missing from it. Although it is clear that initial meaning activation is affected by context and by meaning frequency, meaning selection is largely understudied and the role of competing meanings is unclear. In the experiments described below I looked for evidence of between-meaning competition in meaning resolution, using a task that requires that meanings be resolved (the meaning-fit task). The role of the individual differences ability suggested by previous research to be most relevant, vocabulary ability, was assessed. The goal of the current research is to flesh out models of meaning resolution (and language comprehension) by clarifying the notion of context strength and exploring the nature of the relationship between homograph meanings.

Experiment 1

The goal of Experiment 1 was to replicate the often-observed interaction between context strength and meaning frequency on meaning activation levels in a meaning-dominated task, where context strength is defined in terms of consistency of support for a single homograph interpretation. All sentences were unambiguously biased toward a single meaning but varied in degree of support for an alternate meaning, allowing me to determine whether presence of a word related to an alternate meaning affected homograph meaning activation over and above contextual bias toward the intended meaning, in a task that required meanings to be fully resolved. The vocabulary of each subject was assessed to provide data on individual differences in efficacy of context strength and meaning frequency.

Method

Subjects

Subjects were 62 students of the University of Alberta, participating for course credit. Two subjects had a first language other than English. Their data were discarded, resulting in a total of 60 subjects.

Materials

Meaning-fit task There were 144 sets of experimental sentences and targets; each set of experimental stimuli contained four sentences resulting from the factorial combination of sentence bias (Primary vs. Secondary) and sentence type (Consistent vs. Inconsistent). Sample stimuli are in Table 1; stimuli are arranged in order of predicted difficulty, with Consistent contexts appearing before Inconsistent contexts and primary-biased sentences appearing before secondary-biased sentences. The complete stimulus set is reproduced in the Appendix.

All sentences were five words long and of the same structure (*The (subject) (past tense verb) the (object homograph))*. All sentence contexts were unambiguous in that only one meaning of the homograph provided a plausible interpretation for the sentence (e.g., *The carpenter sawed the board* and *The chairman sawed the board* were unambiguously biased toward the "piece of wood" meaning of *board* because boards of directors cannot be sawed though pieces of wood commonly are; *The chairman instructed the board* and *The carpenter instructed the board* were unambiguously biased toward the "committee" meaning of *board* because pieces of wood cannot be instructed though boards of directors commonly are). The Consistent contexts were biased toward one meaning of the homograph via the inclusion of both a subject and a verb related to the homograph (e.g., *The carpenter sawed the board*). In the Inconsistent contexts, the subject and verb were semantically related to different meanings of the homograph (e.g., *The chairman sawed the board*). The subjects and verbs were not lexically associated to the homograph, as determined by the norming corpus of Twilley et al. (1994; i.e., no respondents gave the subjects or verbs or any derived form of either when asked to provide an associate for the homograph).

Dominance of homograph meanings was determined by the Twilley et al. (1994) norms. Primary meanings were the most common meaning referred to when university students were asked to provide a word related to the homograph; Secondary meanings were either the second most common meaning (for 85% of the stimulus sets) or third or fourth most common meanings (for 15% of the stimulus sets). Median relative meaning frequency for Primary and Secondary meanings was .66 and .17, respectively. The target words were related to the homographs but were not lexically associated with them (they were provided by less than 2% of respondents in the Twilley et al. corpus). *Appropriate* targets were related to the meaning of the homograph supported by the preceding sentence context; *Inappropriate* targets were not related to the meaning of the homograph supported by the preceding sentence but were related to the alternate meaning of the homograph (i.e., they were related to the subject of the Inconsistent context sentences).

The subjects and verbs of the experimental sentences were used no more than twice throughout entire set of stimuli to eliminate trial-to-trial priming effects. The target words were not repeated across stimuli. The sentences contained no homographs other than the sentence-final homograph. There were 144 filler sentences which were of the same form and length as the experimental sentences but contained no homographs and were not semantically ambiguous.

Each subject saw one sentence from each experimental set. Sentence bias and sentence type were both randomly chosen for each homograph but choice of conditions was restricted to 50% Consistent contexts and 50% Primary contexts across the entire experiment for each subject. Target condition was randomly assigned for each sentence but restricted to 50% Appropriate targets across the experiment. Each subject saw all 144 filler sentences randomly intermixed with experimental sentences, followed by Appropriate or Inappropriate targets; target appropriateness was randomly assigned for filler sentences but restricted to 50% Appropriate targets. Thus each subject completed 144 experimental trials, with sentence bias, sentence type, and target appropriateness completely counterbalanced (resulting in 18 data points per subject in each of 8 conditions) and 144 filler trials (72 data points in each of Appropriate and Inappropriate conditions). There were also 24 practice trials presented at the beginning of the task to familiarize the subjects with the experiment, consisting of 12 fillers (50% Appropriate) and 12 homograph trials (50% Appropriate).

Vocabulary. The vocabulary task was the Nelson Denny Vocabulary test (Brown et al., 1981). It consists of 100 multiple-choice items which require subjects to choose the correct word (from five alternatives) to complete a sentence which contains a synonym of the correct answer.

Apparatus

Subjects made responses using a hand-held button box which had two buttons, one labelled "RELATED" and the other "UNRELATED". "RELATED" responses were made with the dominant hand. Stimuli appeared in black on a white screen, with each character subtending approximately one-third of one degree of visual angle. Lights were dimmed to increase contrast.

Procedure

The meaning-fit task was completed first. Subjects initiated each trial by simultaneously pressing two buttons on the button box. Sentences were presented on a computer screen, with total presentation time equal to 300 msec per word + 17 msec per character. Sentences disappeared from the screen and were followed by target words after 100 msec. Targets were surrounded by asterisks (e.g., **DIRECTORS**). Subjects were instructed to respond as quickly and accurately as possible, and were given the following instructions about deciding whether a target word was related to the preceding sentence:

> "Your task is simply to decide if the target word is related to the meaning of the sentence that came before it. If it IS related, press the RELATED button. If it is NOT related, press the UNRELATED button. Although you can likely come up with a relationship between any sentence and word if you try, that's not the idea here. Related trials will be fairly obvious."

Target words remained on the screen until a response was made. This task took about 30 minutes.

Following the meaning-fit task, subjects completed the vocabulary test. Subjects were given verbal instructions describing the task and how responses were to be recorded. They were then asked to read the written instructions in the test booklet, and began once they had indicated that the instructions were understood. They were given 15 minutes to complete the test; not all of the subjects completed all 100 items in this time.

Results

Experimental items

The error rates in the meaning-fit task ranged from 5.5% for the Unrelated fillers to 57.0% in the Secondary Inconsistent Inappropriate condition (e.g., *The chairman sawed the board*, followed by *DIRECTORS*). Because the error rates were very high in some conditions, reaction time data were not analyzed. Rather, analyses were carried out on proportion of related responses in each condition. Median vocabulary score was 67.5, with scores ranging from 28 to 97. A median split was done on the vocabulary scores, and the resulting categorical variable was used in the following analyses. Median vocabulary scores for low- and high-vocabulary readers were 57 and 78.5, respectively.

Analysis of variance indicated a significant three-way interaction between sentence type (Consistent vs. Inconsistent), sentence bias (Primary vs. Secondary) and target appropriateness (Appropriate vs. Inappropriate) ($F(1,59)=30.2$ for subjects; $F(1,142)=14.8$ for items). Means and standard errors are in Table 1 and means and 95% confidence intervals for the *difference between means* are graphed in Figure 3 (see Loftus & Masson, 1994; confidence intervals are adjusted for pairwise comparisons and thus one mean is significantly different from another when their confidence intervals do not overlap). As Figure 3 indicates accuracy in Consistent context conditions was high, with a high proportion of related responses to Appropriate items and a low proportion of related responses to Inappropriate items. Accuracy decreased dramatically in Inconsistent context conditions. There was no effect of sentence bias in Consistent contexts (accuracy was equally high for Primary and Secondary meanings) but in Inconsistent contexts accuracy was lower for Secondary than for Primary meanings.

A second analysis of variance was carried out with vocabulary group as a between-subjects factor. There was a marginal main effect of vocabulary group ($F(1,58) = 3.9$, $p < .10$) and an interaction between vocabulary group and target appropriateness ($F(1,58) = 13.8$). As the means in Table 2 indicate, high-vocabulary readers made fewer incorrect Related responses to Inappropriate items (i.e., fewer false alarms) than did low-vocabulary readers. There were no other interactions with vocabulary group that reached significance (all F's < 2).

Filler items

Average proportion related responses was .89 for the Appropriate filler items and .05 for the Inappropriate filler items. There was an interaction between vocabulary group and target appropriateness ($F(1,58) = 8.5$), indicating that high-vocabulary readers made fewer incorrect Related responses to Inappropriate filler items than low-vocabulary readers (.02 and .09, respectively) while high- and low-vocabulary readers did not differ in proportion of Related responses to Appropriate filler items (.90 and .88, respectively).

This interaction was of the same form as that found for the experimental stimuli. Incorrect Related responses to Inappropriate items (whether homographs are present or not) can be the result of considering only the sentence-final word rather than the entire sentence context in making a meaning-fit decision. It may be the case that low-vocabulary readers tend to consider the context in its entirety less often than high-vocabulary readers. Because this difference was found for nonhomograph fillers as well as homograph stimuli and did not vary with other experimental conditions (sentence type and sentence bias) it consequently is only tangential to the concerns of this paper.

Discussion

In unambiguous contexts which provided support for a single homograph meaning only, subjects were highly accurate at resolving primary and secondary homograph meanings. When contextual cues provided inconsistent but still completely unambiguous support for meanings, accuracy was dramatically affected for both primary and secondary meanings, though more so for secondary meanings. Although the error rates were very high in the most difficult conditions, error rates in the easy conditions were low, indicating that subjects were carrying out the task as instructed. These data replicate earlier demonstrations of an interaction between context strength and meaning frequency. In the strongest (Consistent) contexts, meaning frequency effects were eradicated, but in the Inconsistent contexts primary meanings maintained an advantage over secondary meanings. Such data demonstrate that temporary changes in meaning activation produced by context can overwhelm more permanent levels, strengthening the contention that word meanings are not fixed entities but are in fact strongly dependent on local, moment-to-moment considerations.

Although this replication of the context strength by meaning frequency interaction was an important demonstration, the data are more interesting on another level. The sentence contexts used were such that an alternate meaning of the homograph was completely implausible (in any but metaphorical terms, which subjects were explicitly told to avoid). In spite of this fact, subjects were induced on a surprisingly large proportion of trials to choose the contextually-inappropriate meaning of a homograph by the simple inclusion of a single word more related to the alternate meaning than to the contextually-appropriate meaning. Although previous research has shown that contexts which are unambiguous (biased toward one meaning only) are more effective than ambiguous contexts (e.g., Dopkins et al., 1992; Holmes, 1979), the present data demonstrate that unambiguous contexts which contain information related to an alternate meaning are less effective than unambiguous contexts which contain information related to a single meaning (see also Reder, 1983). Resolution of a homograph meaning can be profoundly affected by the activation of alternate meanings. Normally, the language comprehension system is remarkably powerful, capable of resolving ubiquitous ambiguities with such efficiency that they are rarely even noticed by the comprehender in everyday discourse comprehension. In the present case, reductions in accuracy of as much as 37% occurred simply by including a single word more related to the unintended meaning of the homograph than to the intended. How does this disruption in processing come about?

In the meaning-fit task, subjects are given a sentence followed by a target word. Their task is to compare the meaning of the target word and the meaning of the sentence, and to decide if they are related or unrelated. Presumably, reading of the sentence results in the generation of a representation (probably stored in working memory) of the meaning of the sentence as a whole. The subject's task is essentially to compare this sentence-level representation with the semantic representation of the target word. This process will occur in the context of priming (positive or negative) of the target word from the individual words in the sentence, as a result of spread of activation and inhibition in the lexicon. Thus the subject's response will be based not only on the match or lack thereof between the sentence-level representation and the target word, but also on the degree of activation of the target word.

Because all of the sentence contexts were entirely unambiguous, simple in structure, and presented at a relatively slow rate, it is assumed that subjects usually generated a sentence representation that reflected the intended meaning of the sentence (i.e., the Appropriate meaning). The strength of this representation could very likely vary with degree of subject-verb consistency, but it is assumed that in general subjects generated an appropriate sentence representation. This claim is further supported by a pilot study in which error rates to targets completely unrelated to the sentence (e.g., *TRAIL* following *...the board)* were negligible regardless of subject-verb consistency. If subjects were not comprehending Inconsistent sentences then error rates would be expected to be high regardless of target type. (Note also that the minimal error rates in this pilot study are further evidence that the high error rates observed were not simply due to the presence of homographs but rather were due to competition between meanings). It seems reasonable to assume that on most trials Appropriate targets matched sentence-level representations while Inappropriate targets did not.

In the Consistent contexts (e.g., *The carpenter sawed the board*), Appropriate targets (e.g., *PLYWOOD*) would be strongly primed by the individual words in the sentence. This in combination with the matched sentence-level representation would make a Related decision easy, leading to the very high proportion of related responses in this condition. Inappropriate targets (e.g, *DIRECTORS*) would not be activated by any of the words in the sentence except the homograph. Any inhibition of the "committee" meaning of *board* by the "wood" meaning would in fact lower the activation level of *DIRECTORS*. Along with the mismatch to the sentence-level representation, an Unrelated decision would be easy to reach and proportion related responses to Inappropriate targets would be low, as was found.

In the Inconsistent contexts (e.g., *The chairman sawed the board*), the Appropriate target would still match the sentence-level representation as in the Consistent contexts, but priming of the Appropriate target would be reduced relative to Consistent contexts, thus making a Related decision less easy to reach than for the Consistent contexts. There are two possible sources for this reduction in priming. First, the subject of the Inconsistent context (e.g., *chairman*) would not prime the Appropriate target (e.g., *PLYWOOD*). Second, the subject of the Inconsistent context would prime the inappropriate meaning (e.g., "committee") which could inhibit the appropriate meaning. In the first case, lower accuracy on Inconsistent contexts would be due to *decreased priming* of the Appropriate meaning. In the second case, lower accuracy on Inconsistent contexts would be due to *increased inhibition* of the Appropriate meaning (from the Inappropriate meaning).

Although the sentence-level representation generated for the Inconsistent contexts would not match the Inappropriate targets (e.g., *DIRECTORS* following *The chairman sawed the board*), this mismatch would not lead to an easy Unrelated decision for the Consistent Inappropriate condition, for the same two possible reasons as above (either because *chairman* isn't related to the Appropriate "wood" meaning or because *chairman* is related to the Inappropriate "committee" meaning--and to the target). Thus the observed increase in (incorrect) proportion related responses to Inappropriate targets.

The higher proportion of (incorrect) related responses to Inappropriate targets for the Secondary-biased sentences (e.g., *The carpenter instructed the board,* followed by *PLYWOOD*) than for Primary-biased sentences (e.g., *The chairman sawed the board,* followed by *DIRECTORS*) occurred because of the higher base level of activation of the "wood" meaning (this account assumes that the *carpenter/PLYWOOD* relation and the *chairman/DIRECTORS* relation are equally strong).

As stated above, the lower accuracy on Inconsistent contexts relative to Consistent contexts could be due to a lower level of priming of the Appropriate meaning or a higher level of inhibition of the Appropriate meaning (or both), either of which would make response decisions more difficult. The data from Experiment 1 do not distinguish between these two possibilities, but the distinction is important. Evidence for the second possibility is evidence for between-meaning inhibitory links.

In order distinguish between the two alternatives, a baseline for comparison is required which differs from both the Consistent and Inconsistent contexts in a single aspect only. The Consistent and Inconsistent contexts differ in their subject noun, with the subject of the Consistent contexts being related to the Appropriate meaning and the subject of the Inconsistent contexts being related to the Inappropriate meaning. The subject of the baseline context must thus be neither related to the Appropriate meaning nor related to the Inappropriate meaning; it must be unrelated to the homograph altogether (though it must of course be a plausible subject for either meaning). Experiment 2 employed such a baseline.

Experiment 2

In Experiment 2, contexts that provided unambiguous support for one meaning of a homograph but included a subject unrelated to the homograph were employed, in addition to the Consistent and Inconsistent contexts from Experiment 1. This provided a baseline condition from which to examine activation and inhibition of homograph meanings. If a consistent subject activates a meaning, then accuracy should be improved in Consistent contexts relative to Baseline contexts. If meanings inhibit one another, accuracy in the Inconsistent contexts should be worse than that in Baseline contexts. If meanings are not mutually inhibitory, accuracy on Inconsistent and Baseline contexts should be equal. Under the latter hypothesis, the "wood meaning" of board should be equally active following *The chairman sawed the board* and *The pilot sawed the board* because *chairman* and *pilot* are equally unrelated to the "wood meaning" of board.

Method

Subjects

Subjects were 64 students of the University of Alberta, participating for course credit. Data for two subjects with a first language other than English were discarded. Data for another subject were discarded due to a malfunctioning button box (used to collect responses). This resulted in data from a total of 61 subjects.

Materials

Materials were identical to Experiment 1, with the exception that one experimental condition was added to the stimuli for the meaning-fit task. For each set of experimental stimuli, baseline contexts were created for the primary and secondary meanings of the homograph. These were created by replacing the subject of the corresponding Experiment 1 contexts with a neutral subject that was consistent with both meanings of the homograph but not explicitly related to either meaning (i.e., the subjects were not given as responses to the homographs in the Twilley et al., 1994 norms). Examples appear in Table 3; as in Experiment 1, stimuli are arranged in predicted order of difficulty. The full set of Baseline contexts appears in the Appendix. The resulting sentences were unambiguous in that only one meaning of the homograph was plausible. Each subject saw one sentence from the set of six sentences for each homograph (3 levels of sentence type by 2 levels of sentence bias), followed by a target (either Appropriate or Inappropriate). All factors were completely counterbalanced and randomly assigned, as in Experiment 1. There were thus 12 data points per subject in each of 12 cells for the experimental conditions. Each subject also completed 24 practice trials, including 12 fillers (50% Appropriate) and 12 homograph stimuli (50% Appropriate).

Procedure

Procedure was identical to Experiment 1.

Results

Error rates were again very high in some conditions (ranging from 3.3% for Inappropriate fillers to 51.9% in the Secondary Inconsistent Inappropriate condition); thus reaction time data were not analyzed and analyses are based on proportion of Related responses. The vocabulary data for one subject were discarded; this subject's score was an outlier (more than 3 standard deviations below the mean of all 61 subjects).

Median vocabulary score for the remaining 60 subjects was 69 (range = 42-97). A median split was done on the vocabulary scores and ANOVA's used the resulting categorical variable. Low- and high-vocabulary median scores were 61 (n = 29) and 82 (n = 31), respectively.

Experimental items

There were significant two-way interactions between between sentence type and target appropriateness (F(2,120) = 340.6 for subjects; F(2,268) = 180.0 for items) and between sentence bias and target appropriateness (F(1,60) = 58.7 for subjects; F(1, 134) = 14.4 for items). The three-way interaction between sentence type, sentence bias, and target appropriateness was not significant in the subjects analysis (F(2,120) = 2.0) and was marginally significant in the items analysis (F(2,268) = 2.8). Means and standard errors are in Table 3 and means are graphed in Figure 4 (the 95% confidence intervals are for the difference between means adjusted for pairwise comparisons, based on Loftus & Masson, 1994).

The interaction betwen sentence bias and target appropriateness simply reflects the greater accuracy (higher proportion related responses to Appropriate targets and lower unrelated responses to Inappropriate targets) achieved on primary-biased sentences relative to secondary-biased sentences. This is largely uncontroversial and reflects the fact that primary meanings by definition are better known to the subjects.

The interaction between sentence type and target appropriateness is of much greater interest. As can be seen in Figure 4, all sentence type means are different from each other. In the Appropriate conditions, there is a large decrement in probability of related responses from Consistent contexts to the Baseline contexts (.84 down to .65) and a smaller decrement from the Baseline to the Inconsistent contexts (.65 down to .57). In the Inappropriate conditions, there is a small increment in proportion of related responses from Consistent to Baseline contexts (.15 to .22) and a large increment from Baseline to Inconsistent contexts (.22 to .48).

The decrement in probability of related responses from Baseline to Inconsistent contexts with Appropriate targets indicates that inclusion of a subject related to the alternate meaning of the homograph (as in *The chairman sawed the board*) does indeed cause interference. Because the subjects of the sentences in the Baseline and Inconsistent conditions (e.g., *pilot* and *chairman*, respectively) are equally unrelated to the intended meaning of the homograph ("piece of wood") and to the target word (*PLYWOOD)* this decrement can only be attributed to the relationship between the Inconsistent subject and the alternate meaning of the homograph (e.g., between the "committee" meaning of *board* and *chairman*). This critical piece of evidence indicates that homograph meanings inhibit one another: Support for one meaning lessens the likelihood of resolution of another.

A potential interpretation of the results of Experiment 1 is that the homograph meanings are irrelevant; the data might be explained by simple priming relationships between the subjects, verbs, and targets. The observed difference between *The chairman sawed the board* and *The pilot sawed the board* with target *PLYWOOD* demonstrates the inadequacy of this interpretation. These stimuli are equally related to the target (unrelated subjects, related verbs and homograph) but result in significantly different probabilities of correct response. Clearly homograph meanings are not irrelevant to subjects' responses.

Incorrect Related responses are more likely in the Inconsistent Inappropriate context (e.g., *The chairman sawed the board* with target *DIRECTORS)* than in the Baseline Inappropriate context (e.g., *The pilot sawed the board* with target *DIRECTORS).* In this case, however, there is also an (interfering) relationship between the Inconsistent subject and the target word, so the interference effect is larger than in the Appropriate conditions.

The small decrement in proportion related responses in Consistent Inappropriate conditions relative to Baseline Inappropriate conditions (e.g, *The carpenter sawed the board* vs. *The pilot sawed the board* with target *DIRECTORS)* indicates that there is a facilitatory effect of a consistent subject. In this case both subjects are equally unrelated to the alternate meaning of the homograph (a committee) and to the target word, and the decrement in incorrect responses in the Consistent condition can be attributed to the relationship between the Consistent subject (*carpenter*) and the intended meaning of the homograph (a piece of wood). In the Appropriate conditions, the large difference between Consistent and Baseline contexts is a function of both the relationship between the Consistent subject and the intended meaning as well as the relationship between the Consistent subject and the target word. Thus subjects are much more accurate on *The carpenter sawed the board* than on*The pilot sawed the board* with target*PLYWOOD.*

While the above data make it clear that homograph meanings are not completely independent but in fact inhibit one another, it is not clear what the extent of the dependence is. In the hypothetical case of complete dependence, meanings compete for a fixed pool of activation and an increment in the activation of one meaning leads to a corresponding decrement in the activation of the other, in a compensatory fashion. In the case of partial dependence of word meanings the activation level of one meaning does not completely constrain the activation level of alternate meanings.

The level of dependence between meanings in the data from Experiment 2 can be found by examining total related responses to each sentence type across target conditions (e.g,. total related responses to *The carpenter sawed the board,* including both Appropriate and Inappropriate target conditions). If meanings are completely dependent on one another then assuming that proportion related responses is a direct function of meaning activation, any increase in proportion related responses to an Appropriate target should be accompanied by a complementary decrease in proportion related responses to an Inappropriate target (and vice versa). Consequently, total related responses should not vary across sentence type. Given the forced-choice nature of the meaning-fit task total related responses will be approximately 1. Response bias would affect the actual total (making it higher if the bias was toward Related responses or lower if the bias was toward Unrelated responses) but a simple bias toward Related or Unrelated responses would be independent of sentence type. The critical test of meaning dependence is whether sentence type has an effect on total related responses. No variation in proportion related responses across levels of sentence type indicates that the activation level of one meaning completely determines the activation level of another. An effect of sentence type is evidence against complete meaning dependence.

An analysis of variance on total related responses resulted in a main effect of sentence type ($F(2,120) = 31.4$ for subjects; $F(2, 268) = 28.1$ for items). The main effect of sentence bias was not significant nor was the interaction between sentence type and sentence bias (F's < 1). Means, standard errors, and the 95% confidence interval are in Table 4.

Total proportion related responses in the Consistent contexts was .99. Given the pattern of data discussed above, one meaning can be assumed to be strongly active and the other minimally active in the Consistent contexts, and the higher level of total related responses observed in the Inconsistent contexts (1.06) was due to the concurrent activation of both homograph meanings (the Appropriate meaning to a lower degree than in the Consistent contexts but the Inappropriate meaning to a higher degree), while the lower level observed in the Baseline contexts (.87) is due to weak activation of both meanings (intermediate to the Consistent and Inconsistent contexts). Clearly the activation level of one meaning does not fully determine the activation level of another. The appropriate model of meaning competition is not one of complete meaning dependence. Furthermore, it is inappropriate to assume that language comprehension involves activation of a single meaning and obliteration of all other possible meanings (as intuition and several extant models suggest). To the contrary, inappropriate meanings almost always remained active past the point of response (i.e., past the point of resolution).

An analysis of variance was done with vocabulary group as a between-subjects factor with sentence type, sentence bias, and target appropriateness as within-subjects factors. Means are in Table 5. There were three-way interactions between vocabulary group, sentence bias, and target appropriateness ($F(1,58) = 6.27$) and vocabulary group, sentence type, and target appropriateness ($F(2,116) = 5.44$). The three-way interaction between vocabulary group, sentence type, and sentence bias did not reach significance (F(2,116) = 1.38), nor did the four-way interaction between all factors (F(2,116) = 2.21).

The significant three-way interaction between vocabulary group, sentence bias, and target appropriateness appears in Figure 5 (the 95% confidence intervals are for the difference between the vocabulary group means, adjusted for pairwise comparisons). The graph shows that the two vocabulary groups do not differ on primary meanings. High-vocabulary readers make significantly fewer incorrect responses to Secondary Inappropriate targets than low-vocabulary readers (.29 and .36 respectively) and, at a marginal level of significance, high-vocabulary readers make more correct responses to Secondary Appropriate targets than low-vocabulary readers (.68 and .62, respectively). Thus, as predicted, high-vocabulary readers show reduced dominance effects compared to low-vocabulary readers due to their greater familiarity with less-common meanings.

I also predicted that due to their inability to efficiently inhibit inappropriate homograph meanings, low-vocabulary readers should make a large number of incorrect Related responses to Inappropriate targets in Inconsistent contexts (when the two homograph meanings were explicitly put into competition). As Figure 6 shows, this prediction was borne out (95% confidence intervals are for the difference between vocabulary group means, adjusted for pairwise comparisons): The only condition in which high- and low-vocabulary readers differed significantly was the Inconsistent Inappropriate condition (.43 and .54 proportion related responses, respectively). Low-vocabulary readers were much more likely than high-vocabulary readers to incorrectly decide that the Inappropriate target (which was related to the subject of the context sentence but not the biased meaning of the homograph) was related to the meaning of the sentence. This is consistent with the notion that low-vocabulary readers were unable to inhibit the inappropriate meaning. There was a smaller and marginally significant effect of vocabulary on Baseline Appropriate responses, with low-vocabulary readers making fewer related responses than high-vocabulary readers (.62 vs. .68). Thus low-vocabulary readers are somewhat more less likely than high-vocabulary readers to resolve a homograph meaning when context is biased but not overly strong.

Filler items

The mean proportion Related responses was .91 (SE = .006) for Appropriate items and .03 (SE = .005) for Inappropriate items. There was no effect of Vocabulary ($F < 1$).

Discussion

The high accuracy on unambiguous contexts in which subjects and verbs were related to the same homograph meaning, observed in the first two experiments, is in part due to activation of the meaning from the subject. Furthermore, the remarkably low accuracy on inconsistent contexts is in part due to between-meaning inhibition fueled by a subject inconsistent with the verb in those contexts. High-vocabulary readers are both more familiar with secondary meanings of homographs and are more facile at meaning inhibition. Thus high-vocabulary readers outperform low-vocabulary readers on secondary-biased contexts (though more so with inappropriate than appropriate targets) and on Inconsistent Inappropriate contexts (when meaning resolution requires inhibition of the Inconsistent meaning).

These data are consistent with a model of homograph resolution in which meanings are activated based on the context in which they appear, with added contribution from pre-stored knowledge about frequencies of meanings. There is between-meaning and context-meaning inhibition, resulting in interference from information consistent with a competing meaning. The effect of these inhibitory connections is potentially strong enough to drastically reduce ability to judge semantic relatedness of words and preceding sentences. Vocabulary ability affected meaning activation at the level of pre-stored knowledge as well as in the selection of appropriate meanings.

The Inconsistent sentence contexts used in Experiments 1 and 2 forced word meanings into competition with one another by including words related to both meanings. Evidence for between-meaning inhibition in contexts that do not explicitly support more than one meaning would increase the generality of the findings from Experiments 1 and 2. Experiment 3 was designed to search for evidence of between-meaning competition using only the Consistent stimuli from Experiments 1 and 2.

Experiment 3

Experiment 3 employed a homograph repetition procedure. This procedure allows comparison of initial and subsequent exposures to a homograph; a change in performance from first exposure to second indicates that the first exposure did affect the second in some manner. In order to eliminate activation of competing meanings from sources other than previous viewing, the homographs in Experiment 3 appeared in contexts which, as much as possible, provided support for only a single meaning of the homograph. The Consistent contexts from Experiments 1 and 2 fulfilled this requirement, as indicated by the very high accuracy for those stimuli. Thus, in Experiment 3, each subject saw each homograph twice in Consistent contexts. The first exposure was biased toward one meaning of the homograph and the second toward the other meaning. This design allowed between-subject comparison of the two conditions of interest: activation of a given meaning *without* prior exposure to another meaning, and activation of the meaning *with* exposure to a competing meaning.

For a given homograph Subject A might have seen the Primary context followed by the Secondary context and Subject B might have seen the Secondary context followed by the Primary. Comparison of the first exposure for Subject A to the second exposure for Subject B, for example, shows the effect of the secondary meaning on the primary, with some important controls. First, the activation level of the primary meaning is assessed in a context which includes absolutely no information associated with the secondary meaning (i.e., the sentence context would positively prime the primary meaning only); any activation of the secondary meaning must come from the first exposure to the homograph (when the secondary meaning only was positively primed by context). Second, this design allowed each sentence context to serve as its own baseline, eliminating the need for a control condition because comparisons are between identical stimuli.

If responses to the first exposure do not differ from responses to the second exposure, then the manipulation must be considered ineffectual. If responses to the second exposure are slower or less accurate than those to the first exposure, then processing of the alternate meaning on the first exposure interfered with resolution on the second exposure due to between-meaning inhibition.

Method

Subjects

Subjects were 67 students of the University of Alberta, participating for course credit. Data for two subjects with a first language other than English were discarded, as were data for three subjects which were contaminated by programming errors, and data for one subject who failed to follow instructions. This resulted in data from a total of 61 subjects.

Materials

Consistent sentence contexts and Appropriate and Inappropriate targets from the first two experiments were used. Every subject saw each homograph twice. The homograph was biased toward a different meaning on each viewing. Repetition (first viewing vs. second viewing) was randomly determined, as was sentence bias (Primary vs. Secondary) and target appropriateness (Appropriate vs. Inappropriate). Thus subjects saw every homograph, either in a primary-biased condition followed by a secondary-biased condition (e.g., *The carpenter sawed the board* followed by *The chairman directed the board*) or secondary-biased followed by primary-biased (e.g., *The chairman directed the board* followed by *The carpenter sawed the board*) . Appropriateness of the target was randomly assigned for each viewing (resulting in four possible combinations for each of the two viewings). Thus there were 8 possible conditions, completely randomized and counterbalanced across subjects, with 18 data points per cell per subject. There were 16 practice trials, consisting of 8 fillers (50% related) and 8 homograph stimuli (50% related).

Procedure

Homograph repetitions were separated by 0 to 46 trials, randomly determined (overall average of 23.5 trials). All other aspects of the procedure were the same as in Experiments 1 and 2.

Results

For half of the trials, the sentence context for a homograph was followed by an Inappropriate target. In these conditions there was the possibility that the contextually-inappropriate meaning of the homograph could be activated by the target (e.g., the presentation of *DIRECTORS* could cause activation of the *committee* meaning of *board* following*The carpenter sawed the board*). This was not likely to have been a strong effect given the very high accuracy found in Experiments 1 and 2 for these stimuli; however data for Inappropriate conditions were excluded from analyses in order to obtain as pure a measure of the activation of the contextually-appropriate meaning as possible. Similarly, incorrect responses on the first viewing of a homograph could be evidence that the alternate meaning of the homograph was strongly activated; this could contaminate processing of the alternate meaning when it appeared on the second viewing. Thus data for second viewings which followed an incorrect response to a first viewing of a homograph were also excluded (even though the response on that second viewing might be correct). In summary, analyses that follow are based on first viewings with an Appropriate target, and second viewings following a first viewing with an Appropriate target that was responded to correctly. This conservative procedure ensured that meaning resolution for the homographs was measured under conditions that minimized influence of inconsistent information. The only interfering information was thus from a previous viewing of the homograph in a context that provided consistent and unambiguous support for the alternate meaning of that homograph.

Because only Consistent contexts were used, error rates were not high (ranging from 3.6% for Unrelated fillers to 16.6% for Secondary Second meanings with Inappropriate targets). Therefore analyses of reaction time data were carried out (using only reaction times associated with correct responses) in addition to analyses of proportion related responses. One subject was an outlier in the distribution of vocabulary scores (less than three standard deviations below the mean); this subject's data were discarded from the vocabulary analyses. Vocabulary scores ranged from 37 to 94, with median = 69. A median split was done on the vocabulary scores and ANOVA's on the individual differences measures used the resulting categorical variable. Low-vocabulary readers had a median vocabulary score of 61 (n = 29) and high-vocabulary readers had a median vocabulary score of 75 (n = 31).

Reaction time analyses

Experimental items

Means and standard errors are in Table 6. The main effect of Repetition was significant ($F(1,60) = 5.5$ for subjects, $F(1,140) = 17.3$ for items). Related responses were 38 ms slower on the second presentation of a homograph than on the first viewing of a homograph. The main effect of sentence bias was not significant ($F(1,60) < 1$). The interaction between sentence bias and Repetition was not significant ($F(1,60) < 1$); thus responses to Primary and Secondary contexts were equally slowed. Results are graphed in Figure 7 (the 95% confidence intervals are for the difference between means at each level of Repetition, adjusted for pairwise comparisons, based on Loftus & Masson, 1994).

Although the number of intervening trials between homograph repetitions was randomized rather than manipulated, an analysis of the effect of number of intervening trials was carried out across the entire data set. Residuals from the regression of first viewing reaction times on second viewing reaction times were calculated, in order to isolate the portion of second viewing times that was not shared with first viewing times; reaction times greater than three standard deviations from the overall mean were excluded. A regression analysis with these residuals as the dependent variable and number of intervening trials as the independent variable was carried out. The regression was significant ($F(1, 1614) = 4.6$; $R = .05$. Figure 8 shows the predicted size of the repetition effect as a function of number of intervening trials. As the figure shows, the repetition effect is very robust, surviving over as many as 20 intervening trials (approximately one and a half minutes).

The interaction between Repetition and vocabulary group was not significant ($F(1,59) = 2.0$) nor were any of the other effects involving Vocabulary group (all F's < 1). Means are in Table 7.

Filler items

Mean reaction time on Related fillers was 904 ms (SE = 23.6), and mean reaction time for Unrelated fillers was 992 ms (SE = 27.8). There was no effect of Vocabulary group on Related response times ($F(1,59) = 1.4$) nor on Unrelated response times ($F(1,59) = 1.0$).

Accuracy analyses

Experimental items

There was no main effect of Repetition in the analysis of proportion related responses ($F(1,60) <1$ for subjects; $F(1,140) < 1$ for items). There was a main effect of sentence bias ($F(1,60) = 26.2$ for subjects; $F(1,140) = 7.8$ for items) with more correct related responses to Primary sentences than to Secondary sentences (.90 and .84, respectively). There was no interaction between Repetition and sentence bias ($F(1,60) < 1$ for subjects; $F(1,140) < 1$ for items). Means are in Table 8.

There was a main effect of vocabulary group on proportion related responses ($F(1,58) = 7.0$) showing that high-vocabulary readers made more correct related responses than low-vocabulary readers (.89 and .85, respectively). None of the interactions involving vocabulary group were significant (F's < 2.1). Means are in Table 9.

The only significant effects in the accuracy analyses showed that in unambiguous contexts containing words related to a single homograph meaning, primary meanings were still more active than secondary meanings and high-vocabulary readers were more accurate than low-vocabulary readers. Critically, the main effect of Repetition seen in the reaction time analyses was not mediated by any error effects: none of the analyses of proportion related responses resulted in a significant effect involving Repetition.

Filler items

Mean proportion related responses was .92 (SE = .006) for the Appropriate fillers and .04 (SE = .004) for the Inappropriate fillers. There was a marginal main effect of vocabulary group on proportion related responses for the fillers, but this effect was tempered by a significant interaction between vocabulary group and target appropriateness ($F(1,58) = 7.3$). While low- and high-vocabulary readers performed similarly on Inappropriate fillers (.03 and .04 proportion related responses, respectively) low-vocabulary readers were less likely than high-vocabulary readers to respond correctly to Appropriate fillers (.90 and .94

proportion related responses, respectively). This effect mirrors the effect of vocabulary seen in proportion related responses to Appropriate homograph items.

Discussion

Responses to homograph meanings were slowed when they were preceded by activation of an alternate meaning, in the absence of any contextual support for the alternate meaning. This demonstrates that homograph meanings inhibit one another even when stimuli are not specifically constructed to activate two meanings. When one meaning is resolved, the other becomes less likely to be resolved even when the other meaning enjoys no contextual support whatsoever. Thus I have found evidence for between-meaning inhibition in two very different situations: When a single context provides support for more than one meaning, and when context provides support for only one meaning but homographs occur in more than one context. These data support the assertion that between-meaning inhibition is a general process and is not specific to either homograph repetition or contexts specifically supporting two meanings.

The repetition effect found in Experiment 3 was remarkably robust. As shown in Figure 8, homograph meanings showed inhibition from competing meanings up to 20 trials after their competitors were activated. Although the negative priming phenomenon seems to be very similar to that found here (interference when information that is to-be-ignored on one trial becomes the to-be-attended information on a subsequent trial), negative priming has been shown to be very short-lived, on the order of less than ten seconds (Neill & Valdes, 1992). Repetition priming has been shown to occur over periods as long as days (Scarborough, Cortese, &

Scarborough, 1977), though of course these are facilitatory rather than inhibitory effects. A clear direction for future research is to determine an appropriate theoretical account of the inhibitory effects found here; a first step will be to further specify the parameters of its occurrence.

A more complete model of homograph meaning resolution

The present data support key aspects of previous models. An interaction between context strength and meaning frequency on the activation level of homograph meanings was observed. There were no effects of meaning frequency in very strong contexts, while primary meanings were more active than secondary meanings in Inconsistent contexts. This type of interaction has been previously demonstrated using priming tasks (e.g., Kellas et al., 1991; Simpson, 1981; Simpson & Krueger, 1991) and is central to the current popularity of context-sensitive models of ambiguity resolution. The present data were obtained with the meaning-fit task, however, and thus demonstrate that the interaction (and the suitability of the context-sensitive approach in general) holds for tasks demanding semantic processing.

In the present research, context strength was defined in terms of degree of support for alternate meanings, and the data show that successful meaning resolution entails not only activation of appropriate meanings (as claimed by Kellas et al., 1991; Rayner et al., 1994; Schwanenflugel & Shoben, 1985; Tabossi, 1988) but inhibition of inappropriate meanings (e.g., Gernsbacher & Faust, 1991a,b; Miyake et al., 1994; Simpson & Kang, 1994; Twilley & Dixon, 1996). In all of the contexts used in these experiments only one meaning of the homograph was contextually-appropriate. Nevertheless, the contextually-inappropriate meaning was chosen by the subjects on a large proportion of trials. By far the most errors of this type were made when the context incorporated a word related to the contextually-inappropriate meaning.

In order to establish discourse coherence, we are continuously required to establish appropriate relations between new information and previous information, as in the meaning-fit task. In geniune discourse, it is likely that there are multiple sources of disambiguation, for example extensive previous context and intonational cues in speech. Furthermore, it is unlikely (other than in puns) for two homograph meanings to be directly relevant in a given utterance. Thus while the stimuli used in the present experiments were not necessarily typical of everyday utterances, they do demonstrate that inhibition plays a powerful role in language comprehension. Inappropriate meanings and context related to them can cause serious disruption in judgements of semantic relatedness.The primary focus of this paper was to explain the processes involved in this large interference effect. Contextual influences have traditionally been credited with inhibitory effects (e.g., Kellas et al., 1991; Gernsbacher & Faust, 1991a,b; Miyake et al., 1992; Simpson & Kang, 1994; Twilley & Dixon, 1996) and the present research supported the contention that context does contribute to the inhibition of inappropriate homograph meanings. However, Experiments 2 and 3 made it clear that homograph meanings also inhibit one another. In a model of the lexicon, homograph meanings must be mutually inhibitory, as well as being influenced by contextual concepts.

Kawamoto (1988, 1993) and Waltz and Pollack (1985) implemented computational network models with mutually-inhibitory meanings.

However, in their models only one homograph meaning could remain active after multiple meanings were initially activated. The present data demonstrate that multiple meanings often remain active well after initial activation. The above models could be appropriately modified by maintaining inter-meaning inhibitory connections but eliminating the assumption that meanings are mutually exclusive. Thus the inhibitory connection between two meanings must not be strong enough to completely overwhelm other (contextual) influences on the meanings.

The most notable model that incorporates the idea that alternate interpretations often remain active well after initial activation is Just and Carpenter's (MacDonald, Just, & Carpenter, 1992; Miyake et al., 1994) model of ambiguity processing, in which alternate interpretations are maintained whenever there are available resources. However, this model does not contain inhibitory mechanisms of any sort: Interpretations are either maintained (activated) by application of attentional resources, or they decay. A modification of the model to include context-meaning and meaning-meaning inhibition is warranted by the present data.

I have been discussing meanings as monolithic throughout this paper. However, the present data do not allow specification of whether inhibitory connections exist at the level of homograph meanings, meaning features, or both. Although most feature-priming accounts give little attention to possible inhibitory effects because they are concerned with activation of contextually-appropriate meaning features, the standard feature priming account could be improved by the addition of inhibitory connections between features associated with alternate meanings. Such connections could explain the present data. In models with both features and concept-level representations of word meanings, the present data could be explained by inhibitory connections between concepts, features, or both. Further research is necessary to determine which type of model is more appropriate.

The work on reader parameters in homograph meaning resolution remains incomplete. A clear role for vocabulary was found in the present experiments, but it is undetermined what particular skill is crucial. Is it that component of vocabulary shared with comprehension, is it knowledge of word meanings, is it ability to use context? The present experiments suggest that variations in knowledge of word meanings and between-meaning inhibition could each be contributing to effects of vocabulary ability, but these data do not allow us to make definite discriminations between these possibilities. A component skills analysis (see for example Carr & Levy, 1990) would be helpful in this regard. Although vocabulary ability is clearly important, the role of working memory cannot be disregarded given that resources must be required to activate or inhibit meanings or meaning features while comprehending. A significant contribution to this area would be the development of a task which does not suffer from restriction of range in a population of skilled readers. Alternatively, we could study populations (e.g., children) for which the lack of variability in reading span is not an issue.

Conclusions

Lexical ambiguity research has proven invaluable to a number of critical issues in the word recognition literature. Most salient is its central role in the modularity/interactionism lexical access debate. While the issues addressed by this debate are certainly important, theory development will benefit from concentration on other issues. Clearly, meaning resolution for homographs is a multifaceted and dynamic process. Complete models must account for effects of context strength and meaning frequency in a range of tasks, through development, and in concert with other reading-related skills. This can only be accomplished by considering meaning resolution in its entirety, from initial activation through further activation or inhibition to final integration into the surrounding context. Once such a broad view is taken, generalization of these and other findings to larger issues is possible. It can be argued that successful resolution of any linguistic ambiguity requires inhibition of competing interpretations as well as activation of appropriate interpretations (see Duffy et al., 1988; MacDonald et al., 1992; and Miyake et al., 1994 for conflicting arguments about similarities in processing between different types of ambiguity). Furthermore, inhibition effects similar to the between-meaning inhibition effects found here have been implicated in paradigms as diverse as low-level visual processing and natural language comprehension (see papers in Dagenbach & Carr, 1994; Waltz & Pollack, 1985); this supports the development of general models of cognition which can account for a range of phenomena without recourse to unmanageable numbers of parameters. Construing the resolution of meaning as a problem of indeterminacy which is resolved by applying basic processes of activation and inhibition to mental structures, as has been done in this paper, is a step in the direction of a general model of language comprehension.

Table 1.
Sample stimuli with mean proportion related responses (and standard errors) for Experiment 1.

Condition	Sentence context	Appropriate target		Inappropriate target	
Primary consistent	The carpenter sawed the board.	PLYWOOD	.86(.015)	DIRECTORS	.16(.021)
Secondary consistent	The chairman instructed the board.	DIRECTORS	.84(.015)	PLYWOOD	.20(.023)
Primary inconsistent	The chairman sawed the board.	PLYWOOD	.63(.019)	DIRECTORS	.43(.019)
Secondary inconsistent	The carpenter instructed the board.	DIRECTORS	.52(.020)	PLYWOOD	.57(.024)

Table 2.
Mean proportion related responses (and standard errors) for target appropriateness by vocabulary interaction in Experiment 1.

	Low vocabulary		High vocabulary	
Condition	**Appropriate target**	**Inappropriate target**	**Appropriate target**	**Inappropriate target**
Primary consistent	.85 (.025)	.20 (.033)	.86 (.018)	.11 (.023)
Secondary consistent	.81 (.024)	.26 (.038)	.86 (.015)	.14 (.019)
Primary inconsistent	.63 (.029)	.47 (.023)	.62 (.024)	.40 (.030)
Secondary inconsistent	.53 (.028)	.63 (.035)	.50 (.029)	.51 (.028)

Table 3.
Sample stimuli with mean proportion related responses (and standard errors) for Experiment 2.

Condition	Sentence context	Appropriate target		Inappropriate target	
Primary consistent	The carpenter sawed the board.	PLYWOOD	.86(.014)	DIRECTORS	.13(.015)
Secondary consistent	The chairman instructed the board.	DIRECTORS	.82(.018)	PLYWOOD	.18(.019)
Primary baseline	The pilot sawed the board.	PLYWOOD	.69(.019)	DIRECTORS	.17(.016)
Secondary baseline	The pilot instructed the board.	DIRECTORS	.61(.023)	PLYWOOD	.27(.023)
Primary inconsistent	The chairman sawed the board.	PLYWOOD	.63(.021)	DIRECTORS	.45(.024)
Secondary inconsistent	The carpenter instructed the board.	DIRECTORS	.52(.020)	PLYWOOD	.52(.023)

Table 4.
Mean total related responses (and standard errors) in Experiment 2. 95% confidence interval = .048.

Sentence type	Primary-biased context	Secondary-biased context	Mean
Consistent	.99 (.019)	1.00 (.028)	.99 (.017)
Baseline	.87 (.028)	.88 (.035)	.87 (.022)
Inconsistent	1.08 (.028)	1.04 (.030)	1.06 (.021)

Table 5.
Experiment 2 mean proportion related responses (and standard errors) for low- and high-vocabulary readers.

	Low vocabulary		High vocabulary	
Condition	**Appropriate target**	**Inappropriate target**	**Appropriate target**	**Inappropriate target**
Primary consistent	.87 (.018)	.13 (.017)	.86 (.022)	.12 (.025)
Secondary consistent	.84 (.026)	.20 (.025)	.80 (.025)	.16 (.029)
Primary baseline	.70 (.032)	.16 (.019)	.69 (.021)	.19 (.026)
Secondary baseline	.54 (.035)	.29 (.029)	.67 (.026)	.25 (.036)
Primary inconsistent	.62 (.032)	.50 (.032)	.64 (.029)	.39 (.033)
Secondary inconsistent	.48 (.023)	.58 (.030)	.55 (.031)	.46(.034)

Table 6.
Mean reaction times (and standard errors) in milliseconds for Experiment 3.

Sentence bias	First meaning	Second meaning
Primary	960 (43)	1006 (47)
Secondary	982 (48)	1013 (43)
Mean	971 (32)	1009 (32)

Table 7.
Mean reaction times in milliseconds (with standard errors) for low- and high-vocabulary readers in Experiment 3.

	Low vocabulary		High vocabulary	
Sentence bias	**First meaning**	**Second meaning**	**First meaning**	**Second meaning**
Primary	961 (57)	988 (61)	907 (40)	973 (54)
Secondary	1000 (67)	1022 (63)	909 (43)	975 (55)

Table 8.
Mean proportion related responses (and standard errors) for Experiment 3.

Sentence bias	First meaning	Second meaning
Primary	.90 (.011)	.90 (.013)
Secondary	.85 (.013)	.83 (.016)

Table 9.
Mean proportion related responses (and standard errors) for low- and high-vocabulary readers in Experiment 3.

	Low vocabulary		High vocabulary	
Sentence bias	First meaning	Second meaning	First meaning	Second meaning
Primary	.88 (.019)	.88 (.019)	.92 (.010)	.92 (.015)
Secondary	.81 (.021)	.82 (.023)	.89 (.011)	.85 (.022)

Figure 1. Proposed model of lexical processing and representation.

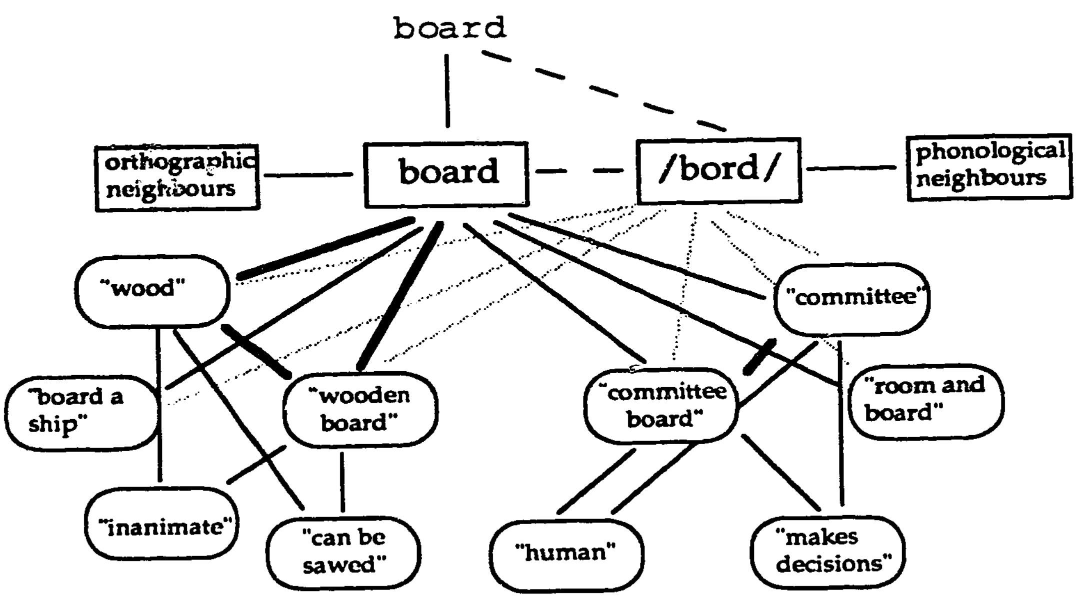


Figure 2. Semantic priming between *carpenter* and *board*.

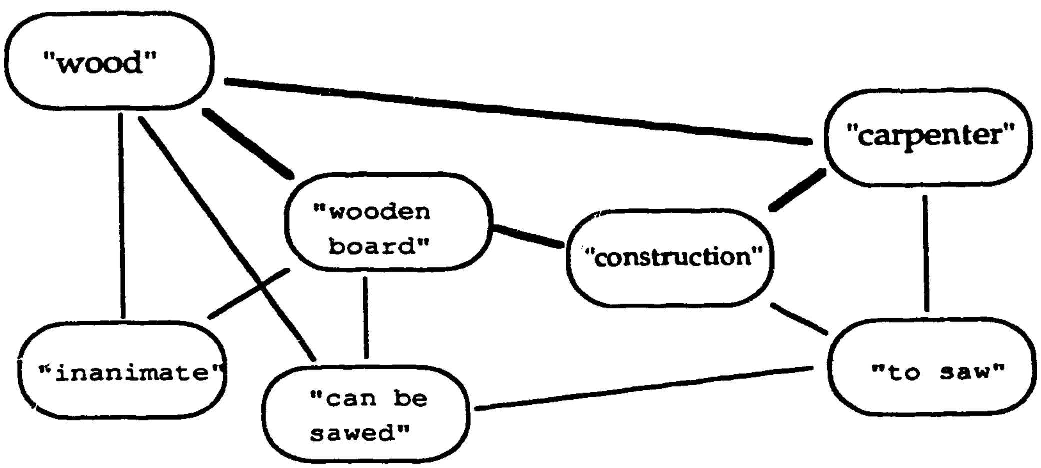


Figure 3. Proportion related responses as a function of sentence bias, sentence type, and target appropriateness for Experiment 1.

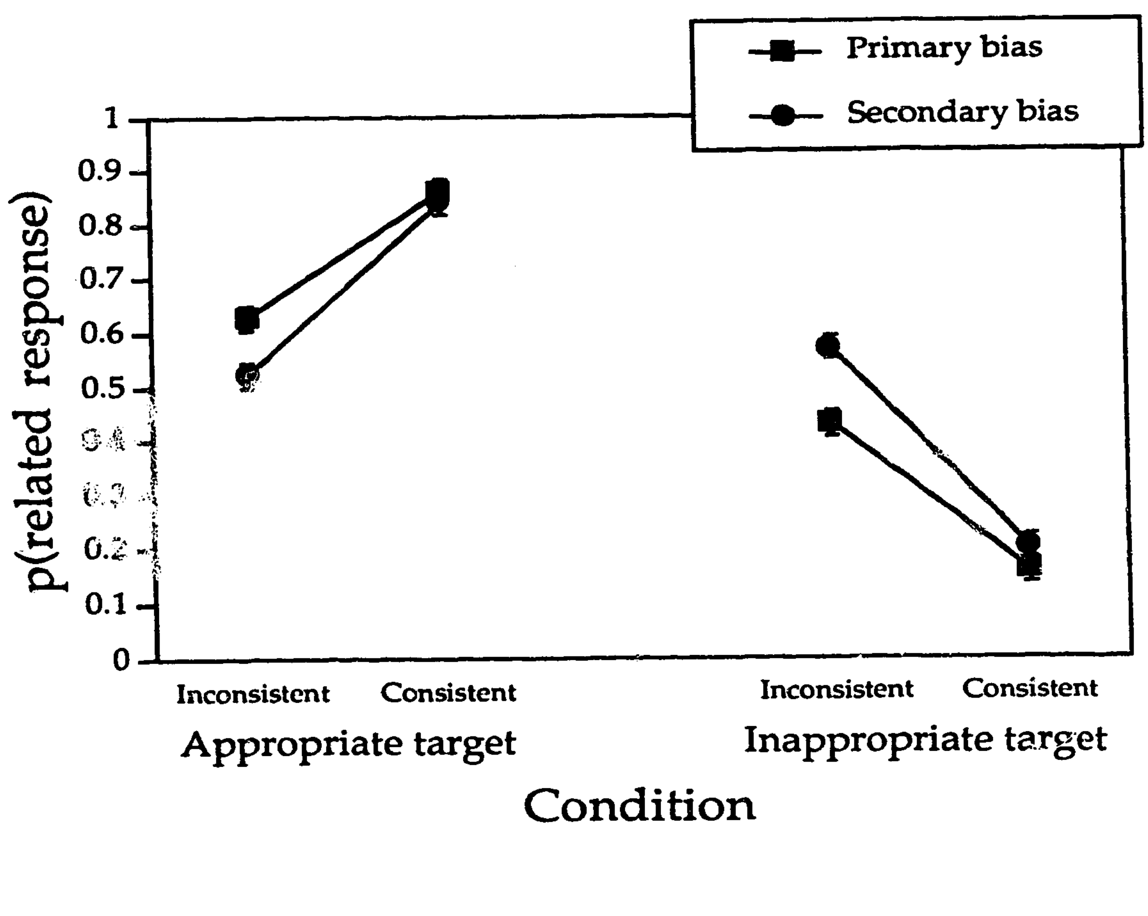


Figure 4. Proportion related responses for Experiment 2.

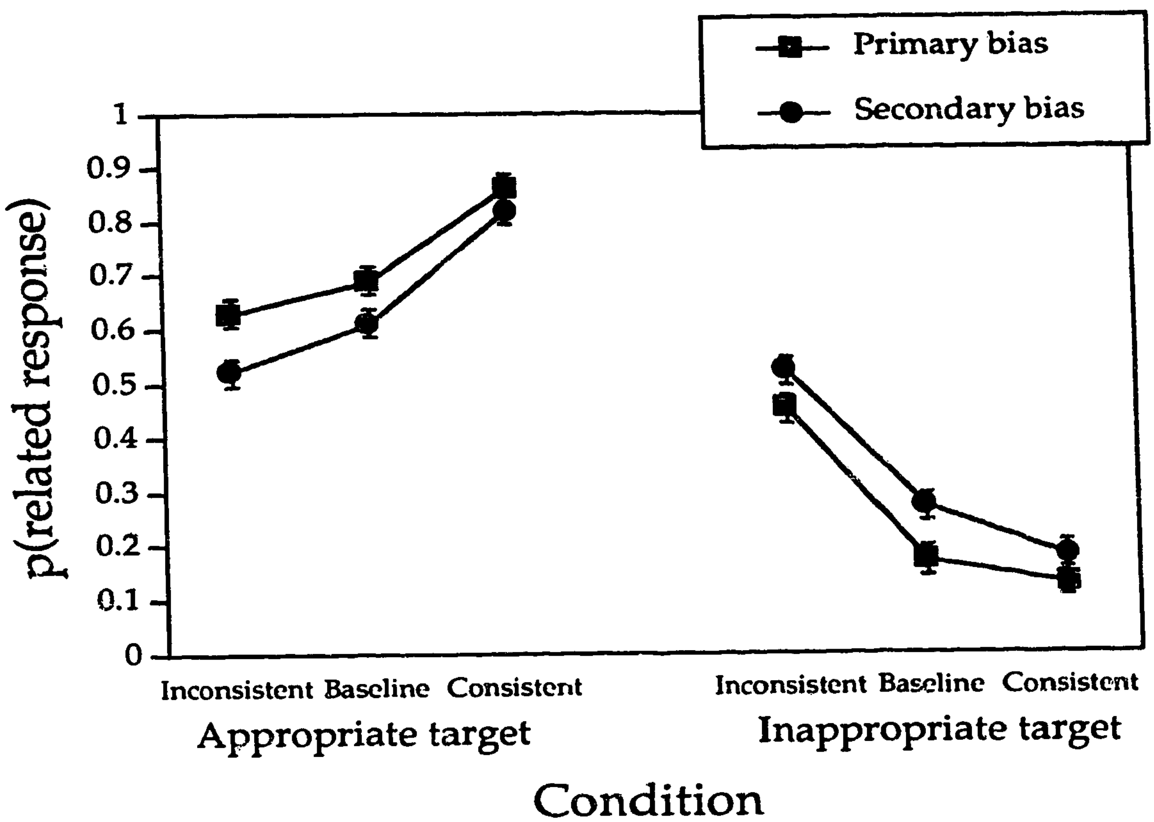


Figure 5. Vocabulary by sentence bias by target appropriateness interaction for Experiment 2.

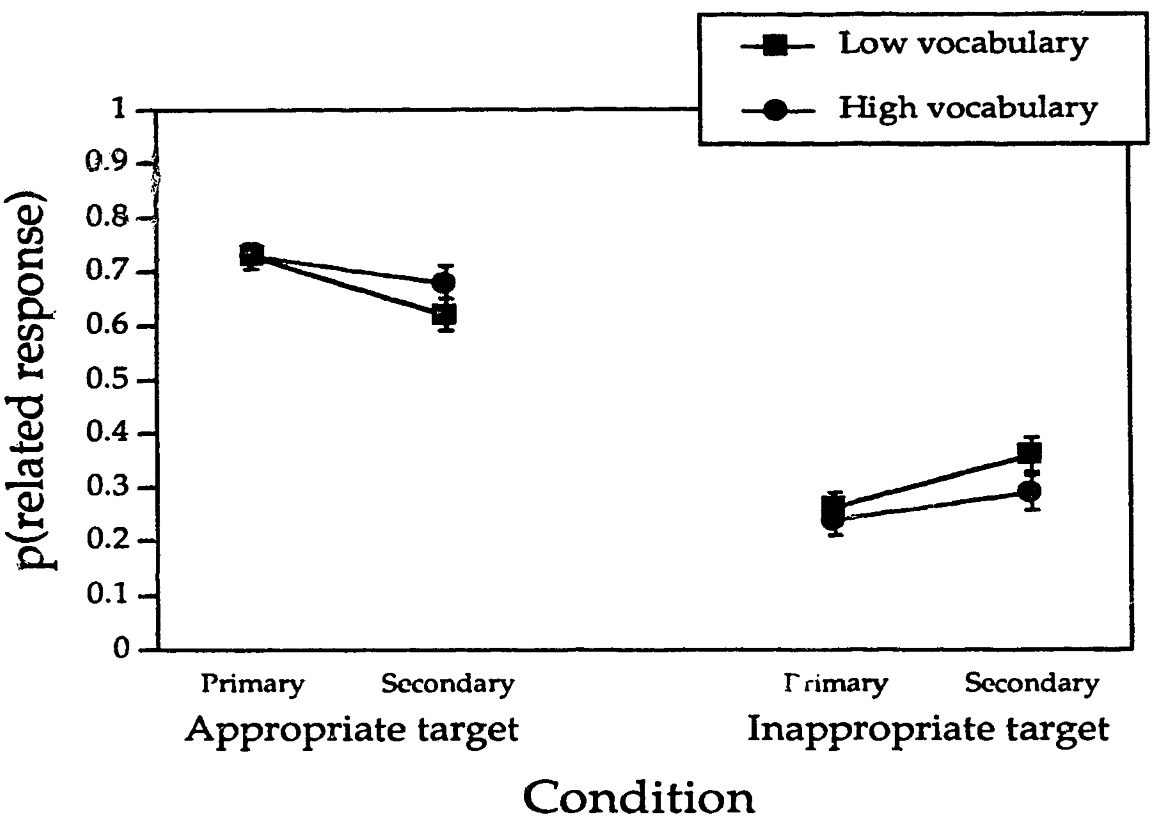


Figure 6. Vocabulary by sentence type by target appropriateness interaction for Experiment 2.

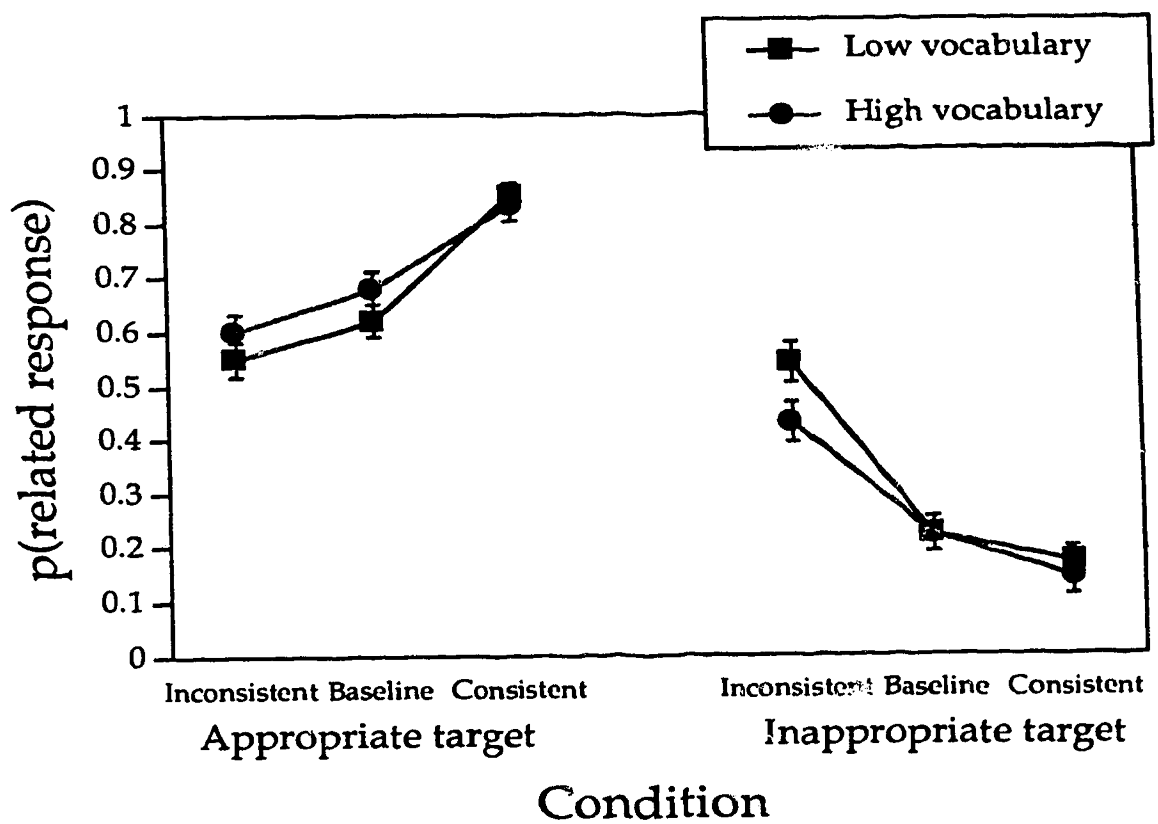


Figure 7. Sentence type by repetition interaction for Experiment 3.

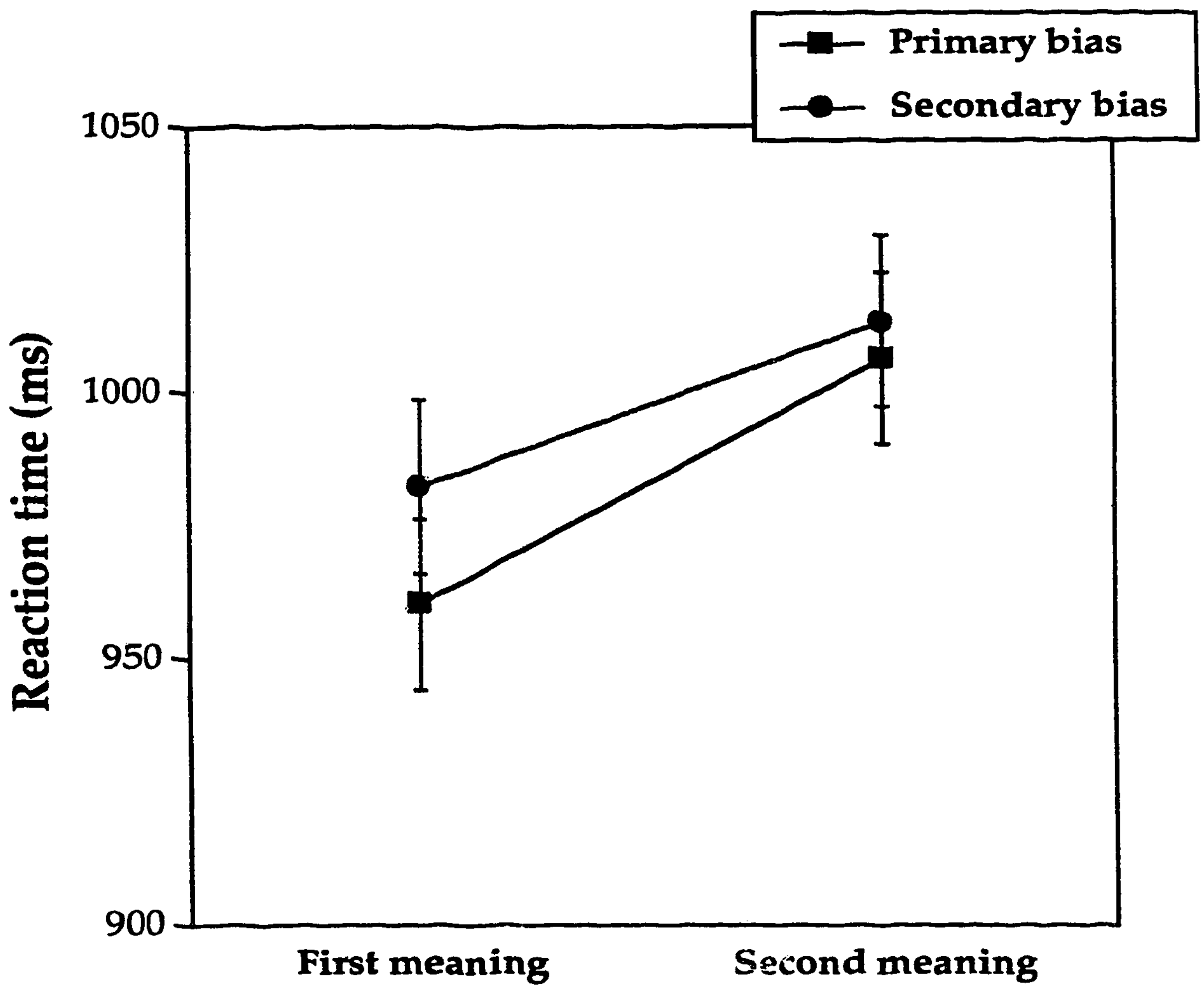
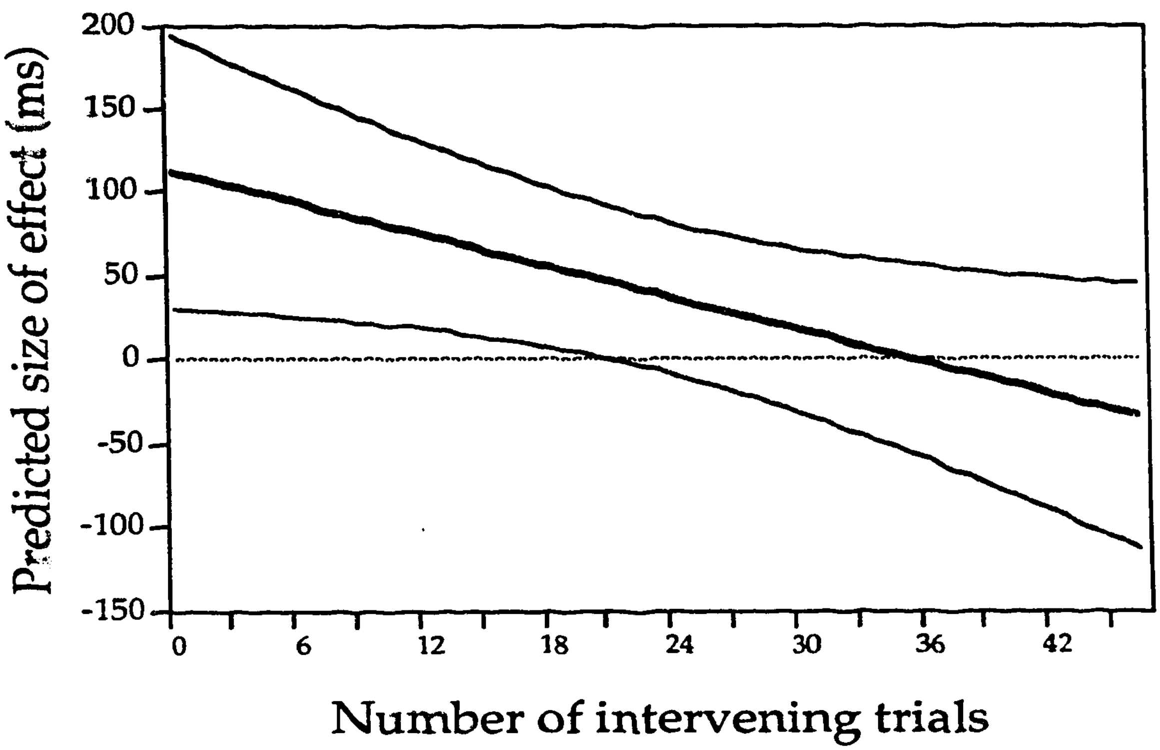


Figure 8. Predicted size of repetition effect (with 95% confidence intervals) as a function of number of intervening trials.



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Appendix

Experimental stimuli (see note below)

The producer/politicians/psychic watched/enforced the act. THEATRE/GOVERNMENT
The journalist/designer/bride read/sewed the article. REPORT/OBJECT
The quarterback/prince/pirate caught/attended the ball. SPORTS/DANCE
The soprano/hairstylist/florist joined/stretched the band. SONG/HAIR
The waitress/inmate/baker closed/sawed the bar. NIGHTCLUB/PRISON
The veterinarian/lumberjack/grandfather heard/stripped the bark. NOISE/WOOD
The singer/angler/gambler tuned/hooked the bass. TUBA/FISHING
The catcher/ranger/dancer swung/captured the bat. STICK/WING
The mechanic/publisher/hairstylist filled/wrote the battery. VOLT/TESTS
The astronomer/workers/cadet reflected/erected the beam. RAY/ROOF
The child/engineer/admirer stacked/surveyed the block. CUBE/CITY
The liar/foresters/medalist contrived/photographed the bluff. PRANK/BUSHES
The carpenter/chairman/pilot sawed/instructed the board. PLYWOOD/DIRECTORS
The partner/trader/critic broke/bought the bond. PACT/SAVINGS
The fiddler/girl/usher poised/sewed the bow. VIOLIN/VELVET
The barber/firefighter/mayor bought/extinguished the brush. BRISTLES/TREES
The inventor/gardener/boss assembled/planted the bulb. FLASH/FLOWERS
The woodworker/leader/drummer finished/hired the cabinet. FURNITURE/POLITICS
The mother/runner/inventor fed/sprained the calf. BEEF/MUSCLE
The skier/pharmacist/veteran wore/sealed the cap. TOQUE/LID
The maid/hiker/seniors washed/explored the cape. CLOAK/COVE
The traveler/banker/welder toured/raised the capital. COUNTRY/INVESTMENT
The policewoman/businesswoman/sportsman reviewed/scratched the case. TRIAL/ATTACHE
The doctor/critic/dignitary removed/hired the cast. CRUTCHES/ACTORS
The guard/botanist/waitress closed/killed the cell. INMATE/TISSUE
The designer/cashier/traveler caused/lost the change. ADJUSTMENT/CENTS
The teller/officer/librarian refunded/read the charge. COST/CRIME
The nurse/pirate/official aerated/buried the chest. LUNGS/CEDAR
The guest/craftsman/terrorist consumed/glued the chip. SNACK/REPAIR
The owner/newcomers/inmate sold/welcomed the company. STORE/NEIGHBOURS
The waiter/voters/villagers scrubbed/applauded the counter. TILE/MATH
The professor/sprinter/sheriff taught/jogged the course. LECTURE/ROUTE
The grandmother/captain/corporal crocheted/steered the craft. SKILL/SHIP
The foreman/zookeeper/queen operated/fed the crane. WORK/STORK
The witness/diver/contestant chased/entered the crook. VILLAIN/BEND
The player/vocalist/uncle broke/missed the cue. SNOOKER/NOTICE
The medalist/secretary/tailor won/erased the dash. HURRY/TYPING
The suitor/chef/guard arranged/boiled the date. NIGHT/RAISINS
The hitman/attorney/sculptor performed/wrote the deed. CHORE/CONTRACT
The teller/geologist/manicurist counted/scraped the deposit. BALANCE/MINERAL
The programmer/anthropologist/wrestler subtracted/dissected the digit. COMPUTER/HAND
The bartender/veteran/dressmaker poured/supported the draft. BREW/MILITARY
The builder/cadet/athlete recharged/learned the drill. ELECTRIC/EXERCISE
The pedestrian/scientist/birdwatcher assumed/examined the fault. GUILT/CRACK
The clerk/welder/lumberjack completed/dulled the file. RECORDS/METAL
The swimmer/builder/fullback reached/applied the finish. GOAL/SHINE
The cook/fighter/cashier folded/pointed the foil. SILVER/SWORD
The drycleaner/shepherd/chairman ironed/called the fold. PLEAT/SHEEP

The wrestler/sergeant/liar applied/trained the force. PRESSURE/CADET
The employee/sculptor/composer read/chiseled the form. DOCUMENT/CONCRETE
The opponents/poachers/postmaster invented/ate the game. COMPETITION/DEER
The winos/contestants/sailor emptied/played the gin. CARDS/DRUNK
The scholar/worker/pharmacist earned/levelled the grade. TRANSCRIPT/SLOPE
The landscaper/cop/politicians raked/confiscated the grass. GROUND/HASH
The drunk/woman/chief broke/wore the habit. ROUTINE/CLOTHES
The boarders/teacher/couple ate/scolded the ham. ROAST/COMEDIAN
The driver/crowd/employee closed/jeered the hood. TRUCK/GANGSTER
The musician/trapper/fiddler played/carved the horn. ORCHESTRA/ANTLER
The admirer/borrower/prince expressed/owed the interest. ATTENTION/PERCENTAGE
The blacksmith/maid/witness shaped/unplugged the iron. HORSESHOE/STEAM
The censors/debater/voters burned/confronted the issue. PUBLICATION/IDEA
The cook/commuter/wizard boiled/entered the jam. GRAPE/TRAFFIC
The principal/astronaut/hobbyist expelled/survived the jerk. CREEP/BUMP
The swimmer/addict/astrologist sprained/rolled the joint. ACHE/DRUG
The bartender/mason/alcoholic squeezed/chiseled the lime. FRUIT/STONE
The garbageman/veterinarian/attorney burned/fed the litter. WASTE/DOGS
The manager/businessman/babysitter painted/blackmailed the lobby. FOYER/ACTIVIST
The camper/pilot/boss chopped/read the log. FOREST/JOURNAL
The student/corporal/bodybuilder declared/saluted the major. SUBJECT/SOLDIER
The technician/priest/blacksmith examined/said the mass. QUANTITY/RELIGION
The hiker/champion/poet bent/cancelled the match. SMOKE/FIGHT
The confectioner/dignitary/dressmaker smelled/toured the mint. FLAVOUR/COINS
The scientist/artist/diver grew/repaired the mold. MILDEW/SCULPTURE
The photographer/hobbyist/girl introduced/glued the model. FASHION/TOY
The farmer/beautician/skydiver trapped/accentuated the mole. DIRT/FRECKLE
The carpenter/manicurist/sergeant drove/buffed the nail. SCREW/CLIPPERS
The courier/composer/drycleaner lost/played the note. LIST/PIANO
The chipmunk/mechanic/hostess ate/tightened the nut. SEED/WRENCH
The patient/caretaker/groundskeeper injured/dusted the organ. KIDNEY/MACHINE
The tourist/trapper/champion opened/followed the pack. LUGGAGE/GROUP
The teacher/manager/coach turned/heard the page. WORDS/BEEPER
The psychic/groundskeeper/citizens opened/pruned the palm. FIST/BRANCH
The handyman/host/geologist nailed/interrupted the panel. OAK/EXPERTS
The fullback/usher/soprano intercepted/inspected the pass. CATCH/MOVIE
The commuter/poet/walker exited/recited the passage. CORRIDOR/READING
The journalist/farmer/pedestrian poised/closed the pen. BOOK/CHICKEN
The birdwatcher/fisherman/president built/caught the perch. REST/HOOK
The lecturer/editor/astronaut filled/erased the period. MINUTES/PUNCTUATION
The professor/apprentice/butler lit/welded the pipe. CIGAR/PLUMBER
The labourer/diner/engineer shovelled/swallowed the pit. TRENCH/NECTARINE
The umpire/singer/dishwasher dodged/lowered the pitch. TOSS/VOICE
The captain/statistician/firefighter landed/calculated the plane. TRAVEL/GEOMETRY
The hostess/coach/producer filled/fired the pitcher. JUG/MOUND
The florist/company/publisher trimmed/closed the plant. FOLIAGE/WORKER
The editor/peasant/parent criticized/plowed the plot. FICTION/SOIL
The repairman/explorer/zookeeper hammered/navigated the pole. POST/COLD
The sailor/customer/inspector entered/tasted the port. OCEAN/LIQUOR
The dishwasher/pusher/botanist scrubbed/grew the pot. COOKING/MARIJUANA
The dieter/shopper/businesswoman gained/spent the pound. FAT/DOLLAR
The bouncer/patron/musician practiced/tasted the punch. ARM/JUICE
The tutor/surgeon/ranger instructed/repaired the pupil. DESK/SIGHT
The opponent/machine/skier smashed/caused the racket. BADMINTON/SOUND

The guest/thief/woman read/robbed the register. HOTEL/CASHIER
The host/government/customer cancelled/named the reservation. APPOINTMENT/LAND
The bride/butler/counsellor lost/heard the ring. JEWELRY/BUZZER
The crowd/bully/foreman heard/kicked the rock. CONCERT/BOULDER
The gymnast/diner/bouncer executed/chewed the roll. SOMERSAULT/DINNER
The student/citizens/camper purchased/elected the ruler. NUMBERS/LEADER
The spectator/player/foresters cheered/washed the runner. HURDLE/SNEAKER
The chef/apprentice/grandmother chopped/consulted the sage. SEASONING/SEER
The dietician/inspector/vocalist calibrated/dissected the scale. MEASURE/LIZARD
The zoologist/president/child trained/applied the seal. AQUARIUM/GLUE
The author/jury/cop deleted/decided the sentence. ESSAY/CRIMINAL
The sheriff/alcoholic/patron heard/poured the shot. RIFLE/DRINK
The walker/murderer/interviewer smashed/loaded the slug. PEST/GUN
The labourer/gambler/banker broke/dealt the spade. TOOL/DIAMOND
The moderator/drummer/drunk introduced/broke the speaker. PODIUM/MUSIC
The driver/addict/priest reduced/injected the speed. PACE/HEROIN
The villagers/bodybuilder/author welcomed/broke the spring. SUN/WIRE
The government/wizard/dietician hired/waved the staff. JOB/WAND
The groom/jogger/boyscout planned/chased the stag. BEER/ANIMAL
The postmaster/official/salesman licked/inked the stamp. ENVELOPE/RUBBER
The secretary/baker/tutor bent/sifted the staple. FASTEN/FLOUR
The astrologist/interviewer/researchers mapped/questioned the star. UNIVERSE/CELEBRITY
The zoologist/chief/barber received/organized the sting. PAIN/RAID
The tailor/jogger/businessman fastened/cured the stitch. HEM/CRAMP
The babysitter/skydiver/fighter sang/reached the story. KIDS/BUILDING
The peasant/kid/hitman raked/melted the straw. FARM/MILKSHAKE
The sportsman/surgeon/doctor practiced/prevented the stroke. MOTION/ATTACK
The salesman/plaintiff/bully hemmed/filed the suit. BLAZER/LAW
The operator/principal/photograph flipped/swung the switch. FLICK/STRAP
The debtor/wearer/explorer paid/removed the tab. CREDIT/LABEL
The clerk/preschoolers/poachers stapled/enjoyed the tag. RECEIPT/CHASE
The librarian/mother/fisherman taped/wiped the tear. SHEET/SORROW
The terrorist/acupuncturist/waiter bombed/massaged the temple. HOLY/BRAIN
The scholar/censor/woodworker started/banned the term. UNIVERSITY/EXPRESSION
The artist/busboy/repairman broke/spent the tip. PENCIL/PAY
The dieter/groom/angler ate/wrote the toast. CRUMBS/CHAMPAGNE
The tourists/dancers/trader cancelled/caused the trip. CRUISE/SLIP
The burglar/athlete/boater raided/performed the vault. TREASURE/FLIP
The sailor/nurse/astronomer steered/cut the vessel. VEHICLE/VEIN
The neighbours/mathematician/beautician disliked/calculated the volume. QUIET/CAPACITY
The gardener/sprinter/gymnast landscaped/gained the yard. HOUSE/FOOT
The aunt/speaker/seller crocheted/repeated the yarn. NEEDLES/TALE

Note: Each stimulus is given in the following format above: The (primary-related subject/ secondary-related subject/baseline subject) (primary-related verb/secondary-related verb) the (homograph). PRIMARY-RELATED TARGET/SECONDARY-RELATED TARGET
Baseline subjects appeared only in Experiment 2.

Filler stimuli

Related fillers

The expert pondered the evidence. CLUES
The client demanded the service. ASSISTANCE
The union negotiated the settlement. RESOLUTION
The lady straightened the skirt. DRESS
The girlfriend watered the dandelion. WEED
The boy squashed the frog. TADPOLE
The wife reported the income. PAY
The family appreciated the help. SUPPORT
The landlord evicted the troublemakers. SCOUNDRELS
The parksworker mowed the cemetery. TOMB
The trucker squealed the brakes. SCREECH
The mountaineer climbed the cliff. HILL
The dictator ignored the embargo. SANCTION
The anarchist seized the castle. WAR
The bullfighter waved the flag. EMBLEM
The king reprimanded the jester. BUFFOON
The rider dismounted the horse. STALLION
The harpist strummed the strings. MELODY
The juvenile accepted the award. TROPHY
The senator refused the pension. RETIREMENT
The bishop blessed the congregation. GATHERING
The northerner hunted the whale. HARPOON
The reporter avoided the question. INQUIRY
The stranger returned the necklace. GEM
The plagiarist fooled the dean. CHEAT
The writer cherished the manuscript. ESSAY
The mourner spread the ashes. CREMATION
The contractor fixed the appliance. STOVE
The warden locked the jailhouse. PENITENTIARY
The friend comforted the victim. CASUALTY
The competitors outsmarted the losers. RIVALS
The public rejected the bid. OFFER
The prisoner resented the shackles. CHAINS
The janitor cleaned the floor. LINOLEUM
The clown exploded the cake. ICING
The cowboy roped the cattle. LASSO
The kidnapper loosened the ropes. KNOTS
The joker insulted the royalty. DUCHESS
The fireman rescued the kitten. MEOW
The electrician wired the garage. CONDUIT
The bailiff escorted the judge. JURY
The clockmaker set the timer. ALARM
The applicant delighted the committee. COUNCIL
The detective searched the premises. LOCATION
The trainee memorized the handbook. DICTIONARY
The mailman dropped the parcel. PACKAGE
The monk honoured the vows. PLEDGES
The nun served the community. SOCIETY
The realtor viewed the home. PROPERTY
The jeweler displayed the collection. VALUABLES

The mime entertained the invalids. SICK
The investigator accused the culprit. BANDIT
The administrator supervised the restructuring. CORPORATION
The pastor delivered the sermon. PREACHER
The interpreter misunderstood the comment. REMARK
The bookkeeper knew the rules. REGULATIONS
The economist projected the result. CHART
The architect redesigned the foyer. ENTRY
The roofer unloaded the shingles. TAR
The miner inhaled the coal. BREATHING
The psychologist collected the data. EXPERIMENT
The dentist inserted the filling. CAVITY
The mortician dressed the body. COFFIN
The decorator installed the fixtures. LIGHTS
The linguist diagrammed the paragraph. CLAUSE
The consumer returned the product. MERCHANDISE
The physician bandaged the toe. GAUZE
The biochemist isolated the molecule. ATOM
The optometrist presented the eyechart. VISION
The anthropologist studied the migration. JOURNEY
The hygienist cleaned the tooth. FLOSS
The draftsperson sketched the auditorium. GYM

Unrelated fillers

The programmer typed the answer. PAINT
The sociologist explained the behaviour. FUNNEL
The advertiser approved the concept. BRUSH
The buyer recommended the parka. AXIS
The manufacturer rebuilt the engine. PUNK
The educator praised the school. DISK
The wholesaler warehoused the inventory. HANDLE
The retailer congratulated the supervisor. LAMPPOST
The curator protected the skeleton. SHORTS
The cartoonist sketched the scene. SPOON
The instructor compiled the worksheet. HUBCAP
The stripper fastened the clasp. SCISSORS
The bachelor regretted the breakup. CHALK
The donor recruited the volunteer. FLAG
The environmentalist condemned the pollution. BRAIN
The theologist outlined the hypothesis. THUMB
The geneticist discovered the gene. PLASTIC
The immunologist disinfected the equipment. BUFFALO
The astronaut left the spaceship. MODEM
The attorney represented the thief. TILE
The groom carried the bouquet. TERRACE
The skier fastened the bindings. PHOTOCOPIER
The barber shaved the beard. CACTUS
The mayor vetoed the agreement. PLASTER
The auditor compiled the finances. LETTUCE
The seamstress altered the bodysuit. COFFEE
The ambassador solved the dispute. COLUMN
The husband renewed the policy. PIN
The father mourned the loss. PLASTER

The newlywed ordered the plates. CANCER
The housewife entertained the visitors. VALENTINE
The monarch banished the traitor. ORANGE
The beekeeper extracted the honey. LIVER
The adult challenged the election. WOLF
The legislator asked the constituents. SHOULDER
The historian discovered the dynasty. LUGGAGE
The merchant untied the bundle. DEBATE
The daughter inherited the bracelet. HALLWAY
The fellow charmed the nanny. PARROT
The actress hated the playwright. SNOWBALL
The society expected the ritual. RASPBERRY
The toddler flushed the toilet. FORK
The hostage smuggled the information. PICKLE
The assistant polished the silverware. ACNE
The butcher froze the meat. SANDBOX
The stenographer positioned the earphone. PORK
The analyst tallied the total. RIBBON
The rabbi performed the ceremony. HORIZON
The negotiator offended the trader. MASCOT
The lunatic discrupted the proceedings. HONOUR
The gypsy foresaw the future. WATER
The adjuster settled the problem. BALLAD
The accountant added the expenses. BATHROOM
The bricklayer mixed the cement. TROPICS
The meteorologist predicted the storm. VIDEO
The chiropractor felt the bone. HOLIDAY
The dispatcher relayed the message. MOTEL
The psychiatrist prescribed the medicine. TICKLE
The archaeologist catalogued the artifact. KETCHUP
The clergyman founded the clinic. RESTAURANT
The marketer revealed the strategy. GINGER
The geographer traveled the continent. JELLY
The purchaser disliked the radio. DEODORANT
The bellhop carried the suitcases. DRAGON
The peddler discontinued the item. GRAVEL
The milkman delivered the butter. COMMA
The obstetrician delivered the infant. COSTUME
The biologist studied the amoeba. DOOR
The financier supplied the paperwork. DOLPHIN
The ecologist protected the birds. EQUATION
The employee forfeited the uniform. KISS
The florist ordered the roses. ELEPHANT