EFFECTS OF MEANING-BASED RELATIONSHIPS AND GOAL-DRIVEN PROCESSING ON SEMANTIC PRIMING IN OCULAR RESPONSE TASKS

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ABSTRACT

Renske S. Hoedemaker: Effects of Meaning-Based Relationships and Goal-Driven Processing on Semantic Priming in Ocular Response Tasks
(Under the direction of Peter C. Gordon)

Semantic priming is very robust in tasks involving the recognition of words in isolation, such as lexical decision tasks, but is quite limited during text reading. In five experiments, we evaluated the role of meaning-based relationships and the mechanisms of priming across two different ocular response tasks. Across word recognition (Experiments 1 and 3) and Lexical Decision tasks (LDT, Experiment 2), associative relationships emerged as the strongest predictor of priming, and the magnitude of the priming effect was not affected by specific semantic relationships. Distributional analyses showed that the effect of priming was concentrated in the slow tail of the distribution, and the relationship between baseline response speed and magnitude of priming was similar across recognition and LD tasks. These results suggest that meaning-based priming is a retrospective mechanism that primarily affects cases in which word recognition is more effortful, independently of task demands at the decision or response selection stage. When task-related processing goals directed attention towards non-semantic information (Experiment 3), semantic priming was reduced relative to baseline response speed, indicating that semantic priming may be relatively task-invariant but does depend on the availability of attentional resources at the semantic level. We also investigated how meaning-based relationships affect the planning and execution of forward saccades during reading by manipulating parafoveal preview of the target and post-target words (Experiments 4 and 5). We did not find evidence for the hypothesis that semantic relatedness primarily affects the L2 stages

of EZ Reader account, as was suggested by the lack of semantic priming on fast responses in the LDT. Instead, it appears that semantic priming effects have an activation floor of at least 300 ms. This time-based account of priming explains differences in distributional priming effects between manual and ocular responses, as well as the fleeting nature of priming effects during sentence reading.

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INTRODUCTION

The extraction of meaning from written words requires processing at many levels of representation, ranging from perception of the visual stimulus to orthographic and phonological analysis of letter strings, to selection of a lexical entry and activation of relevant semantic representations. Because effective experimental techniques have been developed for studying recognition of isolated words at these different levels, visual word recognition has long been a test bed for evaluating general models of cognitive processing (e.g., Balota, 1983; Masson, 1995; Meyer & Schvaneveldt, 1976; Neely, 1977; Plaut & Booth, 2000; Ratcliff & McKoon, 1988; Rumelhart & McClelland, 1986). Of course, word recognition is also studied because it is an essential component of reading, a task with considerable functional importance. Studies of the recognition of words presented in isolation and during text reading have yielded highly consistent evidence about many facets of word recognition (Kuperman, Drieghe, Keuleers, & Brysbaert, 2013; Schilling, Rayner, & Chumbley, 1998), suggesting there is a substantial amount of overlap between the processes required for successful performance on isolated word recognition tasks and the reading of text for comprehension. However, the phenomenon of semantic priming is a notable exception, showing robust effects in tasks involving the recognition of words in isolation, but effects that are much smaller – or absent altogether – in tasks involving text reading.

Semantic priming refers to facilitation in the processing of a word when it is preceded by a related word. Meyer and Schvaneveldt (1971) first demonstrated this effect for response times in the *lexical-decision task* (LDT), where participants make speeded judgments categorizing letter strings as words or nonwords. A substantial body of subsequent research has established some boundary conditions on semantic priming in LDTs as well as speeded pronunciation tasks (Balota & Lorch, 1986; Forster, 1981; Keefe & Neely, 1990), but within those boundaries the effect is very robust (de Groot, 1984; Hutchison, Balota, Cortese, & Watson, 2008; McNamara & Altarriba, 1988; McNamara, 2005; Neely, 1977; Shelton & Martin, 1992). Semantic priming effects have been taken to reflect fundamental mechanisms of retrieval from memory (Masson, 1995; McNamara, 1992; Plaut & Booth, 2000; Ratcliff & McKoon, 1988), and true relations of meaning within the organization of semantic knowledge (McNamara, 2005). Accordingly, semantic priming is a foundational component of many influential models of word recognition, memory retrieval, and general cognitive functioning, such as spreading activation models (Anderson, 1983; Collins & Loftus, 1975) and distributed network models (McRae, de Sa, & Seidenberg, 1997; Rumelhart & McClelland, 1986).

Semantic priming during sentence reading may be observed in the form of reduced word reading times for targets preceded by a related word earlier in the sentence. In stark contrast to the abundance of evidence for robust priming in isolated word recognition tasks, reading studies using eye tracking have provided only a few demonstrations of such effects. Priming effects during sentence reading appear to be heavily constrained by the syntactic structure of the sentence (Carroll & Slowiaczek, 1986; Morris & Folk, 1998), and are easily overridden by message-level factors such as congruity, predictability and presence of discourse context (Camblin, Gordon, & Swaab, 2007; Morris, 1994; Tabossi, 1982; Traxler, Foss, Seely, Kaup, & Morris, 2000). For example, Morris (1994) observed within-sentence priming effects only in cases where the target word was congruent in the sentence context, even though the lexical context was kept constant across congruent and incongruent context conditions. Priming on the target word ‘mustache’ as a function of the related prime ‘barber’ was shown for *The gardener* *talked as the barber trimmed the mustache*, but not for *The gardener talked to the barber and trimmed the mustache*. Similarly, Camblin et al. (2007) demonstrated a strong influence of global discourse coherence over local sentence-based relationships. Eye-tracking measures showed effects of within-sentence lexical association, but only when sentences appeared in isolation or in larger but incoherent discourse contexts. When the same sentences were presented in a coherent larger discourse context, priming effects between associated words were strikingly absent.

Given the robust nature of the semantic priming effect in isolated word recognition tasks and their prominent role in the development of models of memory and language processing, it is quite surprising that the evidence for semantic priming during sentence reading is so limited. If semantic relationships represent true relations of meaning within the organization of semantic knowledge, or if semantic priming effects are the result of a fundamental processing mechanism underlying word recognition, we would expect the effects of priming to scale up more directly from processing individual words to reading meaningful sentences. This discrepancy raises two important questions regarding the nature of semantic priming. First, the nature of meaning-based relationships for which priming is observed remains relatively underspecified. It has been well documented that priming is observed for words that are associated or 'go together' as defined in terms of free-association norms (e.g., Nelson, McEvoy, & Schreiber, 1998). However, efforts to further characterize association in terms of distinct semantic relationships have yielded mixed results, and typically have not found semantic relationships to be better predictors of priming than associative relationships (McNamara, 2005). Second, the lack of robust priming during sentence reading invites a new perspective on the question of what processing mechanisms underlie the semantic priming effect. The current project addresses the role of meaning-based relationships and priming mechanisms in the context of task-based, goal-driven processing during word reading in ocular response tasks. First, we investigated a new hypothesis based on preliminary results regarding the nature of meaning-based relationships and their effect on priming across tasks. Second, we examined the mechanisms by which priming affects word recognition during reading using distributional analysis, which allowed us to move beyond the discussion of automatic versus strategic priming mechanisms, and instead focus on the roles of response speed and goal-driven processing across different tasks. The use of ocular as opposed to manual responses allows us to investigate these mechanisms at a time scale that more closely resembles that of word recognition during sentence reading.

The Role of Relations in Meaning-Based Priming

Within the literature on priming in isolated word-recognition tasks, characterization of the prime-target relationship has been a topic of considerable debate. Early studies of priming, including Meyer and Schvaneveldt's (1971) seminal work, defined relatedness in terms of associative prime-target connections. Associative relationships are operationalized using free-association norms, such as those provided by Nelson et al. (1998), in which forward association strength is defined as the proportion of trials on which the target was given as the first response to a cue. Naturally, most associated word pairs are also connected by virtue of other types of relationships across a variety of categories including synonyms, antonyms, category membership, and functional or script relationships (Hutchison, 2003). Importantly, not all semantically related word pairs are also considered associated. For example, *apple* and *cherry* are semantically related as members of the category 'fruit.' However, nobody participating in Nelson and colleagues' norming study responded *cherry* as a first associate to *apple*, so forward association strength for this pair is zero. However, 8% of the participants produce *apple* as a first associate to *cherry*, so the pair *apple – cherry* has a (low) backward association strength of .08.

In addition to semantic and associative relationships, words may be connected by virtue of shared semantic properties or features (McRae & Boisvert, 1998). For example, *apple* and *cherry* share the properties RED, SWEET and ROUND. Paradoxically, what is referred to as 'semantic priming' in the literature often actually describes studies that defined prime-target relatedness based on free-association norms such as Nelson et al.'s, so that the technically correct term is 'associative priming.'

Models of semantic memory generate different predictions about what kind of prime-target relationships will yield priming. Distributed models of semantic memory represent word meaning as sets of connection weights within a highly interconnected network of individual features (e.g.,McRae, de Sa, & Seidenberg, 1997a; Moss, Hare, Day, & Tyler, 1994; Plaut & Booth, 2000). According to these models, priming occurs because word recognition activates the set of features that together form a conceptual representation of the word's meaning, which subsequently facilitates activation of other concepts that share a large number of features with the original word. Accordingly, pairs sharing a large number of semantic features are predicted to show stronger priming than pairs sharing fewer features. In contrast, association-based models of semantic memory posit that words for concepts that are frequently encountered together (whether in language or actual experience) become connected in the mental lexicon independently from semantic or feature-based relationships (e.g., Fodor, 1983; Hino, Lupker, & Sears, 1997; Perea & Rosa, 2002). These models generate the prediction that priming does not depend on the number of features the prime and target have in common, but on the strength of the prime-target association, as may be estimated using free-association norms.

Efforts to uncover the organizational principles of semantic memory by assessing which types of relationships drive priming have encountered two significant challenges: First, consciously controlled, task-driven processes may be able to find relationships between any two words on the fly (Hutchison, 2003). To tap long-lasting patterns of relatedness in semantic memory, research has focused on measuring ‘automatic priming,’ (Lucas, 2000). However, the difficulty of preventing participants from using task-specific strategies and obtaining ‘purely automatic’ priming has created uncertainty about if and when priming effects accurately reflect general, underlying semantic structure (Hutchison, 2003). Second, there is a great deal of natural covariation between association and semantic relatedness or feature overlap (Lucas, 2000; Hutchison, 2003). It is almost impossible to find highly associated word pairs that have no semantic relation, as associative links rarely arise in absence of a meaningful connection (McNamara, 2005). The reverse, finding semantically related word pairs that are not associated, is equally complex, because the operationalization of association relies entirely on normed databases. Depending on how association is defined, the absence of a particular target as the first response to a prime does not mean that there truly is no association between the prime and target (Hutchison, 2003). In addition, both free association norms as well as semantic similarity or feature listings are sensitive to contextual and instruction-specific factors (Hutchison, 2003; McKoon & Ratcliff, 1995). In light of these conceptual and methodological challenges, it is not surprising that attempts to separate effects of association, semantic relatedness and feature overlap have yielded mixed results (see Hutchison (2003) for a review). While some have argued that priming is driven primarily by associative links independent of semantic relationships (e.g., (Shelton & Martin, 1992)); others have demonstrated priming for non-associated but semantically related pairs (e.g., Lucas, 2000; Thompson-Schill, Kurtz, & Gabrieli, 1998), and still others have found evidence for priming based primarily on degree of semantic feature overlap or semantic similarity (e.g., McRae & Boisvert, 1998; Williams, 1996), and some have proposed hybrid models in which lexico-semantic networks are organized according to a mixture of relationships (e.g., Perea & Rosa, 2002; Seidenberg, Waters, Sanders, & Langer, 1984). As a result, when semantic priming effects are employed as a tool for evaluating general hypotheses about the nature of word recognition, or for studying the mechanisms of priming rather than the nature of meaning-based relationships itself, researchers typically use prime-target pairs with medium to high association strength without differentiating between specific semantic connections.

Preliminary data in the current project showed greater priming for prime-target pairs that were antonyms and synonyms than for pairs that were connected through other types of relationships. Synonym and antonym relationships provide an interesting test case for different models of semantic organization. Both synonyms and antonyms overlap almost completely in meaning, thus sharing a large number of features, while the degree of association varies across particular pairs. Some synonym/antonym pairs are highly associated (e.g., *weep – cry, before – after*, Nelson et al. (1998) forward association strengths of .92 and .86 respectively), while others have very low association strength (e.g., *daring – bold, despise – love*, Nelson et al. association strengths of .01 each). Nonetheless, there is surprisingly little research directly comparing priming for synonyms and antonyms to other types of semantic relationships. Thus far, LDTs have shown modest priming for synonym/antonym pairs with no or low association values, suggesting that priming may be driven by overlapping features or semantic connections independent of association (Hodgson, 1991; Perea & Gotor, 1997; Perea & Rosa, 2002). However, these effects did not differ in magnitude from those observed for other types of unassociated but semantically related pairs (e.g., category coordinates) or pairs that were both semantically related and associated, so it is unclear whether synonym/antonym relationships are distinct from other types of semantic connections. In contrast, in a large-scale review of studies investigating priming among semantically related, non-associated pairs, Hutchison (2003) concluded that there was reliable evidence for priming for non-associated synonyms and antonyms as well as pairs sharing a functional relationship, but not for pairs related by virtue of category membership or perceptual similarity. Finally, McKoon and Ratcliff (1995) found that priming for non-associated pairs was dependent on list context, such that reliable effects were observed only in lists that contained a majority of the same types of relationships (e.g., synonyms in a list containing mostly synonym pairs). However, this effect was not unique to synonyms and antonyms, as category coordinates and superordinates showed a similar sensitivity to list context. In summary, synonyms and antonyms provide a unique opportunity for assessing the independent contributions of feature-based relationships and association strength to priming.

Mechanisms of Priming: The Role of Task-Based, Goal-Driven Processing

One explanation for the finding that priming is robust during isolated word recognition tasks but not during sentence reading is that performance on these two types of tasks involves widely different processing goals. Like other tasks for studying the recognition of isolated words, LDTs impose a specific processing goal while also providing an overt measure (response accuracy) of success in achieving that goal. This direct link between the response and the task goal is an important part of the justification for treating *response time* as a measure of the difficulty of word recognition in an LDT. In contrast, the difficulty of word recognition during sentence reading is typically measured by *gaze duration*, the time that a word is fixated during first-pass reading under circumstances where participants are asked to "read naturally," and the explicit task goal, if any, is to extract the meaning of the sentence or larger text (Inhoff, 1984; Morris, 1994; Rayner, 1998). Consequently, the response of advancing the eyes from one word to the next is based on criteria that cannot be assessed directly, and it is well established that eye movements during reading are shaped by many factors, ranging from the limits of visual acuity and temporal constraints on generating saccades to the dependence of comprehension on the integration of meanings from different parts of a text. As a result, linking eye movements to specific levels of word recognition is model dependent, with models of oculomotor control during reading being a focus of intense interest and debate (Engbert, Nuthmann, Richter, & Kliegl, 2005; Gordon, Plummer, & Choi, 2013; Rayner & Pollatsek, 1989; Reichle, Rayner, & Pollatsek, 2003; Reilly & Radach, 2006).

There is evidence that priming during LDTs can be enhanced when participants are able to apply task-specific processing strategies. For example, priming effects are larger when participants are able to generate expectations about the target based on the semantic properties of the prime (*expectancy generation*, e.g. (Becker, 1980)), and when the presence of a prime-target relationship can be used as a reliable cue that the target is a real word (a phenomenon referred to as *retrospective semantic matching* (Forster, 1981; Neely, 1977; Stanovich & West, 1983), or *post-lexical coherence checking* (de Groot, 1984). However, task-based strategies cannot fully explain semantic priming, as the effect has also been observed using experimental paradigms designed to preclude conscious strategic approaches, for example when one related prime-target pair is embedded in a long list of unrelated pairs (Fischler, 1977), when prime-target pairs are embedded in a continuous list of stimuli rather than distinct prime-target pairs (e.g. McNamara & Altarriba, 1988; Shelton & Martin, 1992; Neely, 1991), and when SOAs are shorter than 250 ms and presumably do not allow enough time for active expectancy generation (Neely, 1991). Nonetheless, it has proven extremely difficult to design experiments that fully and reliably prevent strategic processing, creating considerable doubt as to whether it is possible to observe ‘purely automatic’ priming (Hutchison, 2003; McNamara, 2005). As a result, recent discussions of priming in isolated word recognition tasks have moved away from the automatic-strategic dichotomy, and instead have investigated the mechanism of priming within the context of task goals and task-specific priming mechanisms.

Distributional analyses of semantic priming. Analyses of experimental effects across the full RT distribution have generated important new insights into the mechanisms of goal-driven priming. Ex-Gaussian distributions are typically a good fit for distributions of RTs in both isolated word recognition tasks and eye movements during sentence reading, and have shown stable results both within and across experiments (Balota, Yap, Cortese, & Watson, 2008; Balota & Yap, 2011; Staub & Benatar, 2013). The ex-Gaussian distribution is a convolution of a Gaussian and an exponential distribution and is described by three parameters (Ratcliff, 1979). The mean and standard deviation of the Gaussian portion of the distribution are described by μ and σ respectively, and τ represents the exponential component of the distribution. Changes in μ reflect distributional shifts that maintain the general shape of the distribution affecting fast and slow RTs by an equal amount. Changes in σ represent changes in RT variability, and changes in τ represent changes in the amount of skew. Although the resulting distributions are shaped slightly differently, manipulations that cause an increase in the σ and/or τ parameters result in an increase of the magnitude of the effect across the slow tail of the distribution, affecting slow RTs more strongly than fast RTs. The ex-Gaussian distribution is not based on a theory of response time, so the mapping of distributional parameters to cognitive processes requires additional theoretical and empirical support (Balota & Yap, 2011; Matzke & Wagenmakers, 2009). Nonetheless, ex-Gaussian parameter estimates allow us to capture effects of experimental manipulations across the RT distributions.

Distributional analyses of semantic priming during LDT have consistently found an effect of priming on estimates of μ (Balota et al., 2008; de Wit & Kinoshita, 2014; de Wit & Kinoshita, 2015; Thomas, Neely, & O'Connor, 2012; Yap, Balota, & Tan, 2013). This pattern is consistent with a *prospective* priming mechanism, such that related primes trigger the activation of related concepts resulting in a processing advantage or 'head start' for the related compared to the unrelated target (Balota et al., 2008; Posner & Snyder, 1975; Yap, Balota, & Tan, 2013). As this prospective, head-start activation mechanism is initiated before the target is encountered, fast and slow responses benefit equally and the priming effect is consistent in magnitude across the distribution. In addition to μ-based priming effects, additional effects of priming on estimates of σ and τ are occasionally observed. However, these effects are less common, and appear to depend on methodological specifics of the task regarding the stimulus onset asynchrony (SOA) and the proportion of related trials in the experiment (relatedness proportion or RP). Balota and colleagues have found a priming effect on estimates of σ at short (240 ms) but not long (1250 ms) SOAs, while De Wit and Kinoshita (2015) found a τ-based priming effect when the proportion of related trials in the list was high (.75) but not when it was low (.25). Whether expressed as an effect on σ or τ, increased effects of priming across the slow tail of the distribution are typically considered to reflect a *retrospective* prime retrieval process (Balota et al., 2008, Yap et al., 2012, De Wit & Kinoshita, 2014; 2015, Thomas et al., 2012). It has been argued that this retrospective prime retrieval process is specific to the LD task, as priming was found to be strictly μ-based during naming (Balota et al. 2008) and semantic categorization tasks (De Wit & Kinshota, 2015). However, these authors propose different mechanisms by which the retrospective priming process occurs.

According to Balota and colleagues (2008), word recognition times reflect a 'race' between bottom-up information from the target word itself and top-down, retrospectively accessed information about the prime-target relationship. As mentioned, the bottom-up stream of information may benefit from a head start by the prospective, facilitatory effect of the related prime, but only when the SOA is sufficiently long for the prime to be fully processed and initiate its facilitatory effect. At short SOAs, processing of the prime is incomplete at the onset of the target word, resulting in a reduced advantage for the bottom-up processing stream relative to the top-down, retrospectively recruited information about the prime-target relationship. Slow, effortful responses allow more time for this retrospective priming process to affect response times, resulting in larger priming effects in the slow tail of the distribution. An alternative retrospective priming mechanism was proposed by De Wit and Kinoshita (2015), based on an LDT-specific compound-cue model (Ratcliff and McKoon, 1988). According to this model, LD responses are based on a compound cue consisting of information about the target itself (e.g., orthographic and phonological information) as well as information yielded by a process of post-lexical semantic matching. LDT response times benefit from post-lexical semantic matching, as the presence or absence of a semantic prime-target relationship provides a useful cue to the lexical status of the target. Only word targets can be semantically related to the prime, so detection of a prime-target relationship results in a bias to respond 'word,' while the absence of that relationship may result in a bias to respond 'nonword'. As the compound cue develops over time, slow responses allow more time for retrospective semantic matching, creating a larger priming effect in the slow tail compared to the fast tail of the distribution (De Wit & Kinoshita, 2015). Although the semantic matching mechanisms provides a more detailed account of why retrospective priming processes should be specific to the LDT, this version of the compound-cue model does not explicitly account for Balota et al's (2008) finding that the distributional effects of priming vary as a function of prime-target SOA. Since neither bottom-up processing of the target nor the retrospective semantic matching process can begin until the target word is presented, their relative influence on the compound cue and, consequently, response time should be independent from the amount of time available to process the prime.

Prospective and retrospective priming mechanisms have been linked explicitly to meaning-based relationships through the concept of forward and backward association. Using visually degraded targets, Thomas, et al. (2012) found a τ-based priming effect *only* for pairs that were strongly backwards associated, meaning the prime was a stronger associate of the target than vice versa (e.g., *small – shrink),* and symmetrically associated pairs (e.g., *east – west),* while pairs that shared only strong forward associative connections (e.g., *keg – beer)* showed only μ-based priming (see also Hutchison, Heap, Neely, & Thomas, 2014). These results suggest that prospective priming mechanisms primarily depend on forward associative links, as backward associations cannot be accessed until the target becomes available. In contrast, retrospective priming appears to depend primarily on backwards association, as the reader recruits related prime information to facilitate the ongoing process of target word recognition.

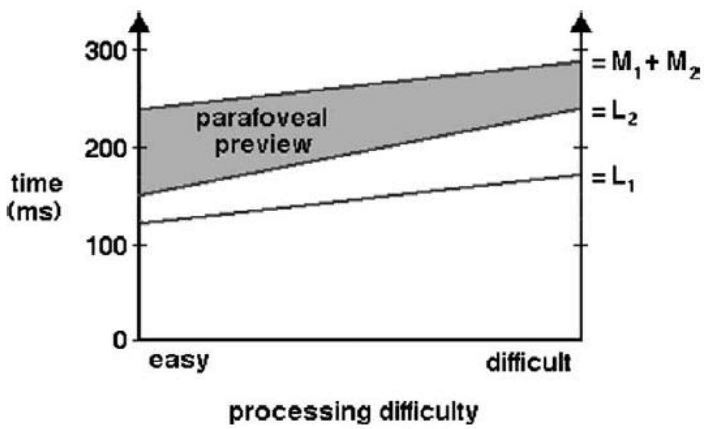
The role of response mode in lexical decision. Distributional analyses of manual LD response times are limited because even the fastest LDs are likely to be much longer than strictly needed for word recognition. For manual LDs, response times average around 600 ms (Balota et al., 2007; McNamara, 2005; Balota & Chumbley, 1984), while reading times for the same words presented in a sentence take only half that time or even less (Inhoff, 1984; Rayner, 1998; Morris, 1994). Given that response times to words in LDTs are strongly influenced by task factors such as type of nonword (Lupker & Pexman, 2010; Stone & Van Orden, 1993), it is likely that processing demands of making an LD account for some portion of the difference between manual LD response times and gaze durations (Rayner & Pollatsek, 1989). In addition, the response of moving the eyes from one word to the next during reading is highly practiced for skilled readers, causing a very tight link between word recognition and saccade execution (Engbert et al., 2005; Gordon et al., 2013; Rayner & Pollatsek, 1989; Reichle et al. 2003; Reilly & Radach, 2006). In contrast, isolated word recognition tasks require participants to use a far less practiced response mode together with response mappings that have little connection to natural reading.

Hoedemaker and Gordon (in press) evaluated the contributions of response mode, task goals, and response speed to associative priming by replacing the manual response mode typically used in LDTs with an eye-movement response. In this study, participants read a sequence of three letter strings and were instructed to move their eyes from one letter string to the next each time the letter string was a word; they were asked to press a button each time the letter string was a nonword. As a result, word reading times were operationally equivalent to key-press reaction times in traditional manual LDTs, while still allowing the eyes to move in a way that resembles regular reading. This *ocular* LDT combines the explicit control of task goals found in LDTs with the ocular response mode used in reading text, resulting in a much faster response distribution than could be obtained using an LDT. Nonetheless, results showed a reliable associative priming effect on the middle (target) word. In addition, the effect was concentrated in the slow tail of the distribution as reflected by a significant effect of relatedness on estimates of τ but not μ or σ. The absence of a priming effect on estimates of μ in a case where mean RTs did show priming is inconsistent with all previous reports of distributional priming effects in manual LDTs (Balota et al., 2008; Yap et al., 2012; De Wit & Kinoshita, 2015), and inconsistent with the interpretation of priming as an encoding-based, head-start effect (Balota et al, 2008; Yap et al., 2012). Moreover, the ocular LDT yielded a τ-based priming effect under conditions that might not be expected to yield such a pattern for manual LDs. The time between the onset of the prime and the target varied depending on the time of LD response to the prime, but at an average of 427 ms, the SOA in this experiment was somewhat slower than the fast SOA experiments by Balota and colleagues. In addition, the proportion related targets (targets being the second letter string on each trial) was .5, but as participants also made an LD response to the post-target word (post-targets being the third and final letter string on the each trial), the overall proportion of LD items preceded by a related word was only .3. The observation of strong τ-based priming at a relatively low RP is inconsistent with the idea that target-prime relationships only contribute to the LDT-specific compound cue in cases where prime-target relatedness provides a strong, task-specific cue to the lexical status of the target word (De Wit & Kinoshita, 2015).

Based on these results, Hoedemaker and Gordon (in press) proposed a mechanism for the effect of priming on ocular responses modelled on the influential EZ reader model of eye movements during reading (Pollatsek, Reichle, & Rayner, 2006; Reichle, Pollatsek, Fisher, & Rayner, 1998). One of the core assumptions of the EZ Reader model is that word recognition occurs in two stages, and completion of each stage has its own effects on saccade programming and the allocation of attention. Saccade programming is initiated upon the completion of the first stage of lexical processing known as the 'familiarity check' or L1. Completion of the familiarity check signals that word recognition is imminent, but actual word identification (stage L2) continues while the saccade to the next target is being programmed. The nature of the L1 familiarity check is not completely established, but recent findings on word skipping during reading (Choi & Gordon, 2013; Choi & Gordon, 2014; Gordon et al., 2013) indicate that it is very sensitive to the lexical status of the letter string being processed. Thus, this L1 familiarity check may be sufficient to accurately perform the ocular LDT task for most words, so that fast responses on relatively easy trials are unaffected by associative prime-target relationships, while slow responses allow for the observation of semantic priming effects that would normally occur during the L2 stage. In contrast, the comparatively small amount of experience that participants have in making manual responses to visual words could be a source of more slack in the connection between basic word recognition and response execution, so that subtle differences in the duration of initial stages of word recognition are less likely to result in observable interactions between priming and trial duration (Hoedemaker & Gordon, in press).

The assumption that L1 processes are not sensitive to associative prime-target relationships leads to the prediction that any associative priming observed in word reading times must be the result of processes taking place during the L2 stage of lexical processing. According to the EZ Reader model, the duration of the L2 stage reading does not affect fixation duration on the current word, but determines how much information can be acquired from the upcoming word in parafoveal preview. Figure 1 contains a schematic depiction of the way in which parafoveal preview benefit is modulated by the duration of the L2 processing stage. Completion of the L2 stage before the saccade triggers a shift of covert attention to the next word, which is then processed in parafoveal preview until the saccade is executed. Consequently, short L2s allow attention to be shifted to the next word more quickly relative to the next saccade, leaving more time for parafoveal processing of the upcoming word which results in decreased reading time once the target word is eventually fixated. If associative priming predominantly affects the L2 stage of lexical processing, priming effects should be observable as a foveal-on-parafoveal effect, affecting reading times on the word or region appearing *after* the target word. Such a mechanism would explain why associative priming effects have been difficult to find during sentence reading, as work on this topic has focused on target rather than post-target word reading times.

Figure 1
From Pollatsek et al. (2006). Schematic depiction of the relationship between the familiarity check (L1) and word identification (L2) stages of word recognition, and two motoric components of saccade planning ($M_1 + M_2$). The figure shows how easier words allow for longer parafoveal preview of the next word by leaving more time between completion of the L2 stage and execution of the next saccade.



Although the assumption that word recognition reflects two separate stages of lexical processing is central to the EZ Reader model, few studies have provided direct evidence for a dissociation of the two stages, or identified variables that exclusively affect one processing stage but not the other. Reingold and Rayner (2006), showed that visual degradation of a target word affects processing time on the target ($word_n$) but does not spillover onto the post-target word ($word_{n+1}$, see also (Drieghe, 2008; Wang & Inhoff, 2010)), supporting the notion that visual quality of the stimulus affects the L1 but not the L2 processing stage. Other variables such as word frequency have been shown to affect reading times on both $word_n$ (e.g., Balota & Chumbley, 1984; Rayner & Duffy, 1986; Rayner, 1998) and $word_{n+1}$ (e.g., Henderson &

Ferreira, 1990; Kennison & Clifton, 1995; Rayner & Duffy, 1986; Rayner, Sereno, Morris, Schmauder, & Clifton Jr, 1989) suggesting they affect both the L1 and L2 stage. To date, no variables have been identified that affect only the L2 stage, such that they would affect reading times on the word following a target but not the target itself.

Goals of the Current Project

The current project has three main goals. First, we investigate the nature of meaning-based relationships that yield priming, and the way in which the effect of semantic relationship type interacts with the processing goals of the task. Post-hoc analyses of earlier experiments suggested that synonyms and antonyms show greater priming than otherwise-associated pairs when the task does not require a metalinguistic judgment, but this effect was not observed for the, inherently metalinguistic, lexical decision task. Experiments 1 and 3 assess how synonyms, antonyms and other-associative relationships affect priming in a word-reading task that does not require a metalinguistic judgment. As will be discussed, the results of the earlier experiment were not confirmed, and this goal will not be pursued further. Second, we investigate the mechanism by which meaning-based relationships affect eye movements during word reading. Specifically, we investigate the role of task-based, goal driven processing on prospective and retrospective priming by comparing the distributional effect of priming on tasks that require a metalinguistic judgment (Experiment 2) and tasks that do not (Experiment 1 and 3), and by assessing distributional pattern of the priming effect in relation to the effect of forward and backward associative strength. In addition, Experiment 3 investigates the extent to which task-related effects of priming can be dissociated from response speed by manipulating encoding difficulty while maintaining the same explicit task goals as Experiment 1. Third, we assess the mechanism by which priming affects the planning and execution of forward saccades. Based on

Hoedemaker and Gordon’s (in press) EZ Reader-based proposal that semantic priming primarily affects the L2 stage of word recognition, Experiments 4 and 5 assess how priming affects foveal and parafoveal processing of visual words by manipulating the availability of parafoveal preview while participants read isolated words in the recognition task.

EXPERIMENT 1 –THE OCULAR RECOGNITION MEMORY TASK

In Experiment 1 participants read sequences of four words and indicated whether a subsequent recognition-memory probe had been among that trial's four words. As such, the goal of the reader was to encode the words for a relatively easy memory task, and word reading times did not reflect task-based, meta-linguistic decision making. Experiment 1 had three goals. The first goal was to investigate the effect of specific meaning-based relationships on priming during word recognition. Pilot data suggested that priming in the ocular recognition task was greater for antonyms and possibly synonyms compared to otherwise-associated prime-target pairs, while no such difference was found during the ocular LDT. Evidence that priming effects are larger for synonyms and antonyms than for otherwise associative pairs would support feature-based models of semantic memory, including distributed network models (e.g Rumelhart & McClelland, 1986; McCrea, et al., 1997) and associative network models in which concept nodes are connected by virtue of shared features (e.g., Collins & Loftus, 1975). Alternatively, the effect of semantic priming may depend primarily on the strength of the associative relationship. If priming is observed only more strongly for items with high association strength regardless of relationship type, this would suggest that eye movements during reading for recognition are primarily sensitive to prime-target co-occurrence contingencies (whether linguistic or experiential), supporting association-based models of priming (Fodor, 1983; Perea & Rosa, 2002; Hino et al., 1997).

The second goal was to assess the nature of the priming mechanism using distributional analyses. Specifically, we aim to assess the extent to which the retrospective priming process found in the ocular LDT (Hoedemaker & Gordon, in press), depends on LDT-specific decision processes, as proposed by De Wit & Kinoshita (2014; 2015) and Balota and colleagues (Balota et al., 2008; Yap et al., 2012). As the task does not require a metalinguistic decision, any observable priming in the current experiment may result from a prospective priming mechanism, in which case we expect an effect of priming on estimates of μ as well as greater priming for pairs with strong forward associative connections. The observation of a τ-based priming effect in the absence of an LD requirement would indicate that retrospective use of the prime-target relationship can occur for the general purpose of word recognition. In this case, we expect to observe stronger priming for pairs with high backward association consistent with Thomas et al.'s (2012) findings.

The third and final goal is to assess the time course of meaning-based priming. The relatively easy recognition task should lead to fast responses times, such that the distributional effect of relatedness can be assessed at a faster baseline than previously possible. If priming effects take a minimum amount of time to be observable in measures of online word processing, assessment of priming across a faster range of responses will help us to identify such a potential threshold. In addition, results from the ocular LDT (Hoedemaker & Gordon, in press) suggest that forward saccades may be executed before semantic processing of the currently fixated word has been completed. In the absence of a lexical decision requirement, this may result in a spill-over effect, such that priming is observed not (only) on the target but also on the post-target word. In contrast to Hoedemaker and Gordon, each trial in the current experiment presents a set of four words instead of three, allowing for more accurate observation of potential spill-over effects on the post-target word.

Method

Participants. A total of 33 undergraduate students from the University of North Carolina at Chapel Hill participated in the experiment for course credit. All participants were native speakers of English with normal or corrected-to-normal vision. One participant was excluded from all analyses because his or her raw target word reading times were more than two standard deviations above the grand mean. Two more participants were excluded because of unusually high skipping rates (at least one word was skipped on over 40% of trials), leaving a total of 30 participants in the analyses.

Materials and design. The stimulus words were presented in sets of four, with the experimental primes and targets appearing in the first and second position of each set. A total of 160 associatively related prime-target pairs were selected from the Semantic Priming Project's (SPP) lexical decision database (Hutchison et al., 2013). All pairs showed strong associative priming in the SPP (mean standardized priming effect: z = .42, sd = .20, range: .20 – 1.10). The experimental pairs were selected to represent three different types of relationships. Forty pairs were synonyms *(garbage - trash),* 40 were antonyms or opposites *(white - black),* and 80 were semantically related by virtue of a different type of relationship not including synonyms or antonyms. Pairs in this other-associates category represented different types of semantic relationships, including category coordinates (*noun - verb),* functional relationships (*blackboard - chalk),* script relations (*airport - plane),* category superordinates (*tuba - instrument),* and uncategorized associations (*compass-direction).* Forward phrasal associates (e.g. *baby-boy*) were excluded, and backward phrasal associates (e.g., *image – mirror*) were avoided as much as possible. Initial categorization by type of relationship was based on the categorization provided in the SPP database, which was then checked by the author as well as an independent coder and adjusted if necessary. See the appendix for all experimental pairs. As shown in Figure 2a, pairs across the three categories were equivalent in mean and range of associative priming in the SPP as measured in LD response time z-scores, $F(2,159) = .26$, $p = .77$, as well as forward association strength (FAS, Figure 2b), $F(2,159) = .09$, $p = .92$, and backward association strength (BAS, Figure 2c), $F(2,159) = .41$, $p = .66$. The stimulus set also represents a range of forward (.01 - .83) and backward (.00 - .82) association strengths, with similar ranges for each of the three relationship types. The word frequency of primes and targets was 3.02 by 51 million (range 1.3 - 4.87) (Brysbaert & New, 2009), mean length was 5.96 letters (range 4 – 14) and mean orthographic neighborhood size was 4.14 (range 0 – 28).

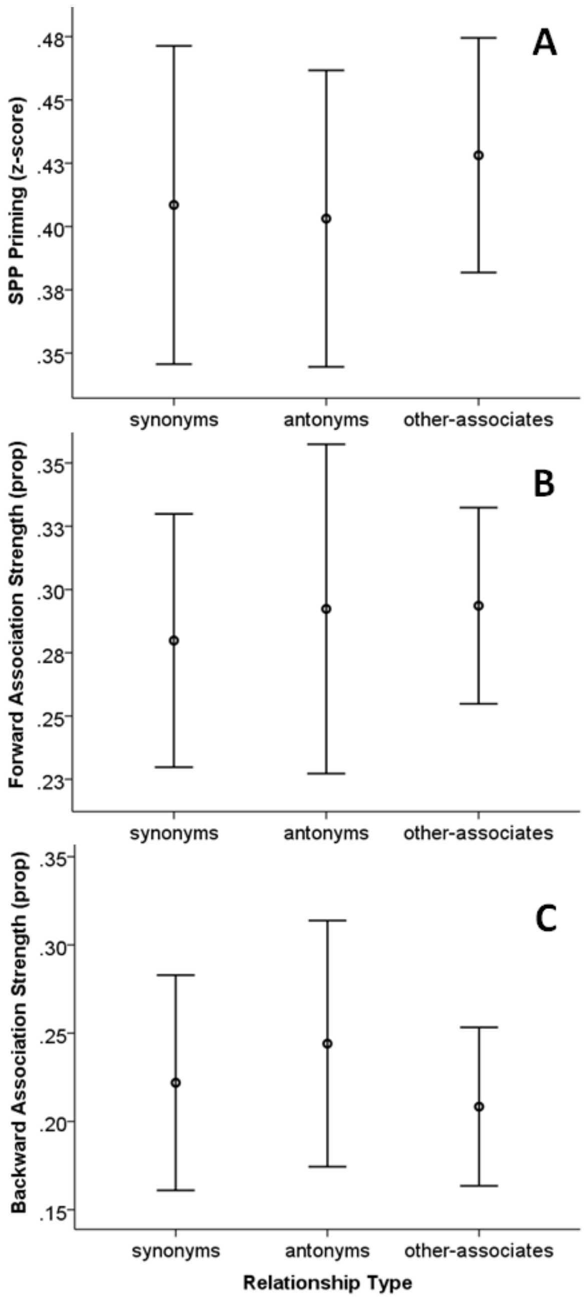


Figure 2

The prime-target pairs in the recognition memory experiments were matched across synonyms, antonyms and otherwise-associated pairs on the standardized priming effect in the SPP (panel A, mean z-score in the unrelated condition - mean z-score in the related condition), forward association strength (FAS, panel B), and backward association strength (BAS, panel C). FAS and BAS values were based on the Nelson et al. (1998) free association norms. Error bars represent 95% confidence intervals of the means.

Unrelated prime-target pairs were created by repairing each prime with a different prime's related target. The related and unrelated pairs were divided into two lists so that each list contained the same prime and target words, varying only the specific pairings of targets and unrelated/related primes. As a result, each subject saw all targets, half preceded by a related prime and half preceded by an unrelated prime. No words were repeated within a list. A third and fourth word were added to each experimental pair to create sets of four. These filler words were selected from Nelson et al. (1998) and did not differ from the experimental stimulus words in length, t(636) = .09, p = .93, frequency, t(636) = 1.43, p = .15, or orthographic neighborhood size, t(636) = 1.01 p = .31. Probe words were selected so that half of the trials containing a related and half containing an unrelated prime-target were followed by a new probe word. The old probes were selected from each of the four positions equally often. The old and new probes did not differ in mean length, t(158) = 1.10, p = .27, frequency, t(158) = .88 p = .38, and orthographic neighborhood size, t(158) = -.75, p = .46.

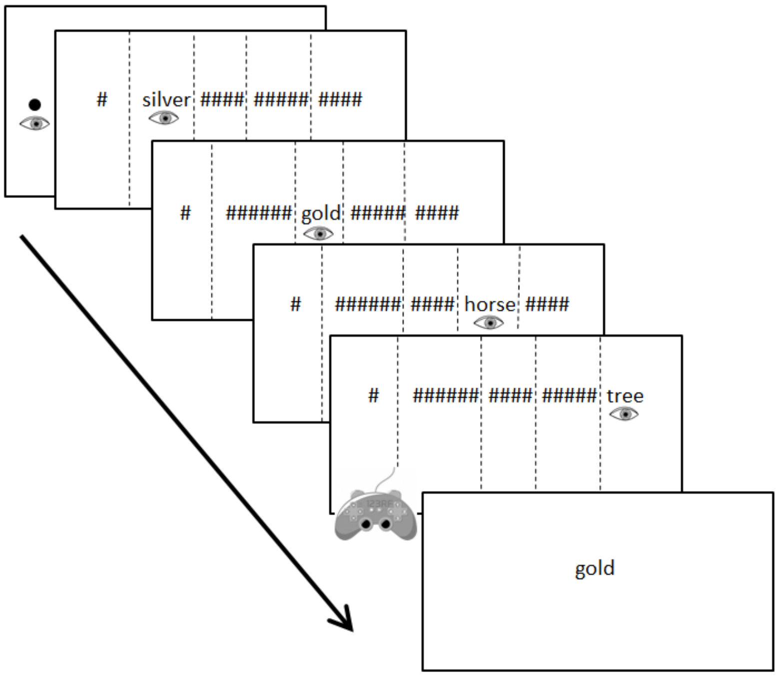
Procedure. Eye movements were recorded in a dimly-lit room from the participant's dominant eye using an SR EyeLink 1000. Eye dominance was determined using the Miles or 'hole-in-the-hand' test (Miles, 1929; Roth, Lora, & Heilman, 2002). Chin and forehead rests were used to minimize head movements. The stimuli appeared on a 22" Samsung LCD monitor at a viewing distance of 57 cm with a 120 Hz refresh rate and a 1680x1050 display resolution. Use of a 20 point monospace font rendered each letter about 11 pixels wide and one degree of visual angle spanned approximately 3 characters. A 9-point calibration procedure preceded each experimental session. After initial calibration, each experimental session started with 10 warm-up trials. These warm-up trials did not contain any of the words used in the experimental list and were excluded from all analyses. Following the warm-up trials, all experimental trials were presented in random order in a single block. Each experimental session lasted approximately 30 minutes.

Participants read each set of four words on a gaze-contingent display while their eye movements were monitored. Participants were instructed to read all four words silently before pressing a key on a hand-held console. The key-press triggered a new screen presenting a probe word. The participant’s task was to indicate whether the probe had been among the trial’s four words or not, indicating ‘yes’ or ‘no’ via a speeded key-press on the same console. No words from the trial were visible while the probe was up, and the probe remained visible until a response was made. Participants received accuracy feedback after every trial.

Operation of the gaze-contingent display is depicted in Figure 3. The start of each trial was marked by a fixation point on the left side of the screen. Once this point was fixated, the next screen appeared containing four masks made up of hash marks. The first mask appeared six blank character spaces to the right of the fixation point, and the subsequent masks were separated by two blank character spaces. Gaze-contingent invisible boundaries were placed in between each mask. The gaze contingencies were set to prevent parafoveal processing and rereading of the non-fixated words. Each word was unmasked only when the eyes entered its region on the screen from left to right. Once the eyes left the word across the right boundary (thus simultaneously entering the next region and unmasking the next word), the mask reappeared and the word was no longer visible regardless of whether the participant made any regressive eye movements.

Figure 3

Presentation of stimuli in the ocular recognition task. Response time was measured as the gaze duration on each word. After reading the fourth word, participants pressed a button which triggered the presentation of the probe word.



Analysis of eye movements. Eye movement measures for the prime, target and third-word position are reported as the fourth-word required a key-press response. Fixations shorter than 80 ms and within 1 degree of a longer, immediately subsequent fixation were merged with the longer fixation by an automatic procedure in the EyeLink software. One item was removed from all analyses due to a stimulus error. Trials on which either the prime or the target was skipped (11.5% of trials) were removed from the analyses, as were trials on which a boundary was inadvertently triggered due to a blink (.5 % of trials) or because the eye fixated on or very near the boundary instead of on the word (7.7% of trials). Finally, trials on which the participant regressed from the target back to the (then masked) prime rather than progressing to the post-target word were also removed (.2% of trials). The excluded trials were distributed equally across the related and unrelated conditions, with an average of 63 and 64 usable trials respectively remaining in each condition. When brief delays in the display change caused a word to be unmasked slightly after the onset of the first fixation, the timestamp of the fixation onset was adjusted to reflect the onset of the word display, excluding any time the participant was fixating the mask rather than the word, resulting in an average adjustment (excluding no-adjustment cases) of 7 ms (range 1 – 86 ms). Finally, a reading time cutoff was determined at three standard deviations above the mean for each position in the triplet in each relatedness condition. Gaze durations longer than the relevant cutoff were removed, affecting 1.7% of all words, equally distributed across the related (1.6%) and unrelated (1.8%) trials.

Gaze duration is the sum of all first-pass fixation durations on a word and is widely used as a measure of lexical encoding in eye-tracking studies of reading. In the context of the recognition memory task, gaze duration was interpreted as a measure of encoding time for each word (Inhoff, 1984; Morris, 1994; Rayner, 1998). Results for three other widely-used measures of first-pass reading are reported for completeness. *Single-fixation duration (SFD)* is the fixation duration for those words that received only one first-pass fixation. *First-fixation duration (FFD)* is the duration of the first fixation on a word regardless of the total number of fixations on that word. *Proportion of single-fixation trials* is the proportion of trials on which a word received only one fixation.

Results

Mean accuracy for the recognition probe responses was 98% (sd = 1.7%, range: 93% - 100%). Gaze durations across the prime, target and third-word position and association condition are presented in Table 1. Mean gaze duration was 303 ms (sd = 27 ms) for unrelated words across all three positions (i.e., middle words in the related-prime condition were excluded) as compared to 411 ms (sd = 48 ms) in the ocular LDT (Hoedemaker & Gordon, in press). Mean gaze durations on individual words were correlated with manual response times in the English Lexicon Project (ELP, (Balota et al., 2007)), r = .36, p < .001, R^2 = .13 (N = 479), and negatively correlated with SUBTLEX (Brysbaert & New, 2009) log word frequency, r = -.317, R^2 = .10, p < .001 (N = 479).

Table 1
Word reading times in Experiment 1. All times in are in milliseconds. Asterisks indicate a significant effect.

		Word Position		
Measure	Condition	Prime	Target	Post-Target
Word GZD (sd)	Related pairs	323 (53)	319 (56)	344 (62)
	Unrelated pairs	330 (61)	329 (63)	343 (63)
	Mean	327 (57)	324 (59)	343 (62)
	Priming	***7***	***10****	***-1***
Word FFD (sd)	Related pairs	248 (39)	281 (43)	286 (42)
	Unrelated pairs	250 (40)	285 (47)	285 (42)
	Mean	249 (39)	283 (45)	285 (42)
	Priming	***2***	***4***	***-1***
Word SFD (sd)	Related pairs	283 (44)	299 (47)	312 (49)
	Unrelated pairs	286 (46)	305 (52)	310 (47)
	Mean	285 (45)	302 (49)	311 (48)
	Priming	***3***	***6****	***-2***
Proportion Single Fixation Trials (sd)	Related pairs	.61 (.19)	.80 (.20)	.71 (.23)
	Unrelated pairs	.61 (.19)	.77 (.21)	.72 (.23)
	Mean	.61 (.19)	.79 (.20)	.72 (.23)
	Priming	***0***	***-.03***	***.01***

Associative relatedness and semantic relationship types. Table 2 shows the mean reading times for the target words across relatedness condition for synonyms/antonyms and other-associate pairs. There was a main effect of relatedness, so that reading times on the target word were shorter in the related compared to the unrelated prime condition for gaze duration, $F_1(1,29)$ = 16.21, p < .001, $F_2(1,157)$ = 11.35, p < .001, and single-fixation duration, $F_1(1,29)$ = 7.32, p < .05, $F_2(1,157)$ = 4.40, p < .05. There was a marginal effect of relatedness on first-fixation duration in the by-subjects analysis but the effect was not significant by-items, $F_1(1,29) = 3.09$, $p = .09$, $F_2(1,157) = 1.88$, $p = .17$. Across relatedness conditions, gaze durations on antonym/synonym targets were shorter than on associated targets, $F_1(1,29) = 7.3$, $p < .05$, $F_2(1,157) = 6.62$, $p < .05$, but there was no difference across relationship types for single-fixation duration, $F(1,29) = .77$, $p = .39$, $F(1,157) = .59$, $p = .45$, or first-fixation duration, $F(1,29) = .01$, $p = .96$, $F(1,157) = .18$, $p = .67$.

Crucially, the effect of relatedness did not differ as a function of relatedness type. Although gaze duration showed a marginally significant interaction in the by-items analysis, $F_1(1,29) = 2.5$, $p = .13$, $F_2(1,156) = 3.5$, $p = .07$, there was no evidence for an interaction based on single-fixation duration, $F_1(1,29) = 1.62$, $p = .21$, $F_2(1,157) = .25$, $p = .62$, or first-fixation duration, $F_1(1,29) = .01$, $p = .99$, $F_2(1,157) =.01$, $p = .94$. Reading times on the third, post-target word did not show effects of relatedness or relationship type on any of the eye movement measures of interest, all Fs < 2.

Table 2
Target word reading times by relatedness and relationship type. All times in are in milliseconds.

		Relationship Type	
Measure (in milliseconds)	Condition	Synonyms/Antonyms	Associated
GZD (sd)	Related	318 (60)	319 (53)
	Unrelated	324 (60)	334 (68)
	Mean	321 (60)	327 (61)
	Priming	***6***	***15***
FFD (sd)	Related	281 (48)	281 (39)
	Unrelated	284 (46)	284 (50)
	Mean	283 (47)	283 (45)
	Priming	***3***	***3***
SFD (sd)	Related	300 (53)	298 (42)
	Unrelated	303 (49)	308 (57)
	Mean	301 (50)	303 (49)
	Priming	***3***	***10***
Proportion Single Fixation Trials (sd)	Related	.81 (.21)	.80 (.20)
	Unrelated	.81 (.20)	.75 (.22)
	Mean	.81 (.20)	.78 (.21)
	Priming	***0***	***-.05***

Multilevel model analysis. Because the effects of interest occasionally yielded results that were not fully consistent in the by-subjects and by-items analyses, and in order to assess the effects of continuous variables forward association strength (FAS), backward association strength (BAS) and SPP priming score, target word reading times were also assessed using multi-level models (MLMs) with subjects and items as crossed random effects (Baayen, Davidson, & Bates, 2008)). The MLMs were fit using the lme4 package (Bates, 2005; Bates, Sarkar, Bates, & Matrix, 2007) in the R Environment for Statistical Computing (Venables & Smith, 2011). All models included random intercepts for subjects and items, and random slopes were included whenever the data allowed (see Table 4) (Baayen, et al., 2008). Separate models were computed for each eye movement measure (gaze duration, single fixation duration, first-fixation duration). For each measure, a control model was built first containing four control variables that might affect the outcome measure: prime and target frequency (word frequency reliably affects reading times in the current data, and word frequency tends to be correlated between primes and targets in related pairs), trial number (there is typically a reduction in reading times over the course of the experiment) and reading time on the prime (in previous work using ocular response tasks, we have found a significant effect of response rhythm within a trial (Hoedemaker & Gordon, in press). Table 3 shows which control variables were significant predictors in each model. The final models contained the significant control variables as well as the predictors of interest: relatedness, relationship type, forward association strength, backward association strength, SPP priming score as well as the interaction between relatedness and each of the other predictors. Significance levels of the predictors in any of the models did not change when non-significant interactions were removed from the model.

The regression coefficients (*b),* standard errors and t values for each predictor in each model are presented in Table 5. As it is not clear how to determine degrees of freedom or estimate *p*-values, we do not report these. However, for large datasets and a relatively small number of fixed and random effects the distribution of t-values approximates the z-distribution. Therefore, we use the two-tailed criterion $t \geq 1.96$ to correspond to a significance test at an alpha level of .05.

The results are largely consistent with results of the ANOVAs. A main effect of relatedness was significant for gaze duration and single-fixation duration, but not for first-fixation duration. There were no main effects of relationship type, forward association strength, backward association strength or SPP priming score, and the effect of relatedness did not differ as a function of FAS, BAS or SPP priming score. Consistent with the ANOVA, the effect of relatedness did not vary as a function of relationship type.

Table 3

T-values for control variables included in the MLM in Experiment 1. Dashes indicate the control variable was not significant in the control model and excluded from the full model.

	Measure		
Variable	GZD	SFD	FFD
Frequency Prime	--	--	--
Frequency Target	-4.21	--	--
GZD Prime	16.86	19.43	18.91
Trial Number	-9.01	-6.25	-3.42

Table 4

Random slopes included in the MLM for Experiment 1. Dashes indicate the random slope was not included in the full model. Asterisks indicate the slope was included in the full model.

	Measure		
Slope	GZD	SFD	FFD
Priming by subjects	--	--	--
Priming by items	--	--	--

Table 5

Results of the MLM for Experiment 1. Rel.Type = Type of Relationship (synonym/antonym or otherwise-associated). Significant t-values are presented in bold.

	Measure								
	GZD			SFD			FFD		
Main Effects	***b***	**SE**	**t**	***b***	**SE**	**t**	***b***	**SE**	**t**
Related	-8.06	2.28	**-3.53**	-4.98	2.10	**-2.37**	-2.294	2.15	-1.06
Rel.Type	1.54	2.41	0.64	-0.11	2.26	-0.05	-2.24	2.36	-0.95
FAS	-16.43	6.74	**-2.44**	-0.18	6.47	-0.03	10.77	6.79	1.59
BAS	8.88	6.04	1.47	5.86	5.74	1.02	4.16	6.01	0.69
SPP Priming	3.98	5.98	0.67	4.71	5.79	0.82	5.57	6.01	0.93
Interactions	***b***	**SE**	**t**	***b***	**SE**	**t**	***b***	**SE**	**t**
Related*Rel.Type	-5.04	4.58	-1.10	-2.99	4.23	-0.71	3.08	4.32	0.71
Related*FAS	-14.86	13.21	-1.13	-12.85	12.09	-1.06	3.60	12.47	0.29
Related*BAS	0.18	11.68	0.02	-9.50	10.76	-0.88	-4.86	11.03	-0.44
Related*SPP Priming	4.881	11.68	0.42	-4.57	10.86	-0.42	-4.52	11.02	-0.41

Ex-Gaussian distribution fit. Because there was no evidence that the effect of associative relatedness varied as a function of semantic relationship type, ex-Gaussian distribution fits were collapsed across relationship types, focusing only on the related-unrelated contrast. We obtained ex-Gaussian parameter estimates for target word reading times separately for each participant in each relatedness condition using the QMPE v2.18 program (Cousineau, Brown, & Heathcote, 2004) for quantile maximum likelihood estimation. Quantile estimates were calculated by ranking RTs for each participant in each condition from fastest to slowest, and dividing them into 11 equally spaced bins. Ten observed quantile estimates were then generated by taking the average of the slowest trial in one bin and the fastest trial in the next bin. Only the fastest trial in the slowest bin and the slowest trial in the fastest bin are used to compute the first and last quantile estimate, so that extremely fast and extremely slow outliers do not affect the quantile estimate. One participant was excluded from the analyses to follow because his or her RT distribution did not fit the typical ex-Gaussian pattern and resulted in outlying values on the distributional parameter estimates. The means analyses reported above were rerun without this subject and none of the effects of interest were changed.

The quantile estimates for gaze duration, single-fixation duration and first-fixation duration are plotted in Figure 4. Naturally, reading times increased across quantiles for all three measures: GZD: $F(1,28) = 194.47$, $p < .001$, SFD: $F(1,27) = 210.55$, $p < .001$, FFD: $F(1,28) = 250.92$, $p < .001$. In addition, gaze duration showed a significant main effect of relatedness, GZD: $F(1,28) = 13.83$, $p < .001$, an effect that was marginal for single-fixation duration, $F(1, 27) = 3.06$, $p = .09$, but not significant for first-fixation duration, $F(1, 28) = .74$, $p = .40$. Crucially, gaze duration and first-fixation duration showed an interaction between quantile and relatedness, indicating that the effect of relatedness increased with RT, as can also be observed from the quantile plots, GZD: $F(1, 28) = 18.38$, $p < .01$, FFD: $F(1,28) = 4.56$, $p < .05$. The effect was marginally significant for single fixation duration, $F(1,27) = 3.32$, $p = .08$. In order to ensure that this interaction did not depend entirely on effects occurring only in the slowest tenth quantile, the

ANOVA was repeated including only the first nine quantiles. Excluding the 10th quantile, gaze duration continued to show a significant relatedness by quantile interaction, : GZD: $F(1,28) = 13.32$, $p < .01$, although the effect of first-fixation duration was now marginal, $F(1,28) = 3.69$, $p = .07$ and the effect on single-fixation duration was no longer significant, $F(1,27) = 1.59$, $p = .22$.

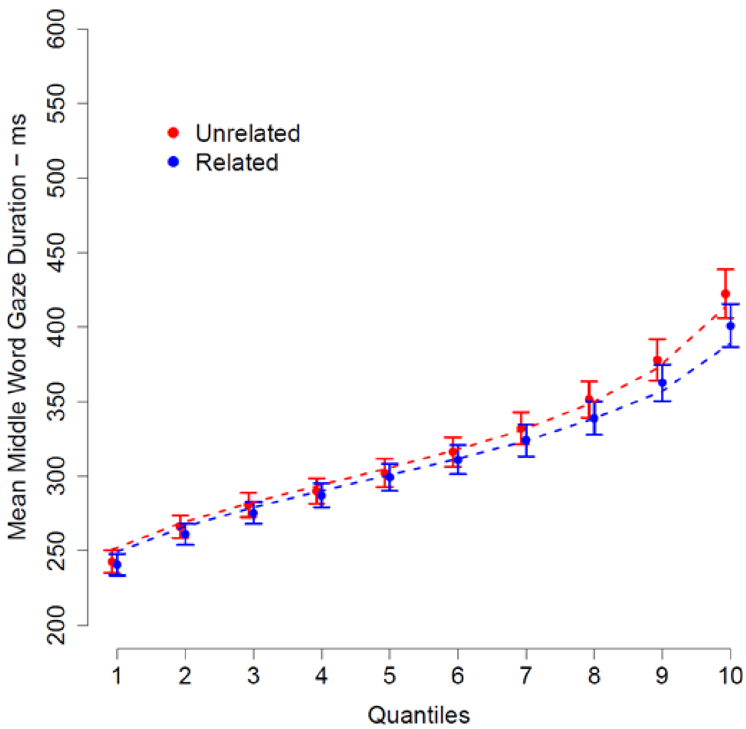
Ex-Gaussian parameter estimates generated by the QMPE program were used as dependent variables in paired-samples t-tests. Average parameter estimates are shown in Table 6. Relatedness did not affect estimates of μ for gaze duration, $t(28) = -1.05$, $p = .30$, single-fixation duration, $t(27) = -1.28$, $p = .21$, or first-fixation duration, $t(28) = -1.51$, $p = .14$. Similarly, there were no effects of relatedness on σ, all ts < 1. In contrast, for gaze duration the estimates of τ were significantly larger in the unrelated compared to the related condition for gaze duration, $t(28) = 3.04$, $p < .01$, and both single-fixation duration, $t(27) = 2.04$, $p = .05$ and first-fixation duration showed marginally significant effects in the same direction,(28) = 1.91, $p = .07$.

Table 6
Ex-Gaussian parameter estimates in Experiment 1. All times in are in milliseconds. Asterisks indicate a significant effect.

		Parameter		
Measure	Condition	Mu	Sigma	Tau
	Related	268 (49)	33 (23)	46 (33)
GZD (sd)	Unrelated	264 (42)	32 (23)	59 (32)
	Priming	***-4***	***-1***	***13****
	Related	249 (31)	42 (20)	28 (23)
FFD (sd)	Unrelated	243 (35)	41 (19)	36 (29)
	Priming	***-5***	***-1***	***8***
	Related	260 (33)	30 (18)	33 (25)
SFD (sd)	Unrelated	256 (28)	29 (17)	41 (26)
	Priming	***-4***	***-1***	***9***

Figure 4

Quantile plot for mean gaze durations on the middle word in the ocular recognition task in Experiment 1 when the target was preceded by a related or an unrelated prime. Quantile estimates were calculated by ranking RTs for each participant in each condition from fastest to slowest, and dividing them into 11 equally spaced bins. Ten observed quantile estimates were then generated by taking the average of the slowest trial in one bin and the fastest trial in the next bin. Quantiles are arranged from fastest to slowest on the x-axis. Error bars show the standard error of the quantile value across subjects and the dashed lines represent predicted quantile values based on mean parameters of the estimated ex-Gaussian distribution.



Discussion

We did not find evidence that priming in the ocular recognition task varied as a function of the type of prime-target relationship or association strength, or that these effects differed across LDT and recognition tasks. Synonyms and antonyms share a large number of semantic features, but did not show greater priming than otherwise associated pairs. Therefore, this experiment does not support distributed network models of semantic organization in which concepts are represented through interconnected sets of features. However, it must be kept in mind that this experiment did not directly manipulate the degree of prime-target feature overlap, but instead compared synonyms and antonyms (both posited to have a high degree of feature overlap by virtue of their semantic relationship) and otherwise associated pairs (which may vary in their degree of feature overlap).

Target word reading times in the ocular recognition task showed no effect of priming on estimates of μ, but effect of priming on estimated of τ was highly reliable. These results indicate that there was little to no effect of priming on fast responses, while the effect of relatedness increased across the slow tail of the distribution. The lack of a reliable μ-based priming effect is consistent with the results of the ocular LDT (Hoedemaker & Gordon, in press), but not with distributional analyses of priming in manual LDT (Balota et al., 2008; De Wit & Kinoshita, 2014; 2015; Yap et al., 2012). As such, these results do not provide evidence for a prospective or head start priming mechanism as proposed by Balota and colleagues (Balota et al., 2008; Yap et al., 2012). We also did not find an effect of forward association strength on the magnitude of priming, which is consistent with the notion that prospective priming processes do not noticeably affect eye movements in the ocular recognition task.

The observation of a reliable τ-based priming effect suggests that prime-target relatedness has a bigger effect on target word recognition on slower, more effortful trials, even when effort is due to inherent difficulties in lexical encoding rather than a word-nonword decision. This observation is inconsistent with the notion that retrospective priming processes observed in LDT are strictly associated with LDT-specific decision processes as suggested by De Wit and Kinoshita (2014; 2015) and Balota and colleagues (Balota et al., 2008; Yap et al., 2012). However, we did not find evidence that the magnitude of the priming effect was related to backward association strength, a finding that is inconsistent with Thomas et al.'s (2012) assertion that retrospective priming processes depend on the availability of target-to-prime backward associations. There are two possible explanations for this result. First, Thomas et al, treated backwards association as a discrete variable, and only pairs that were strictly forward associated did not show retrospective priming. The prime-target pairs in the current study represented a range of backward association strengths, and most had a backward association value that was at least somewhat greater than zero. Therefore, it is possible that retrospective priming is a discrete effect that may occur any time the backward association strength is greater than zero, rather than a continuous effect such that the magnitude of the retrospective priming effect depends on backward association strength. Alternatively, our results may indicate that τ-based effects of priming do not necessarily reflect a process by which participants are actively checking for a relationship between the target and the prime. Instead, the semantic representation of prime may continue to develop in activation strength while the target is being processed, and this process is allowed more time and influence on slow trials. As such, slow trials may reflect stronger priming than fast trials even though participants are not recruiting the target-to-prime relationship in an active, goal-driven manner. This hypothesis will be explored in more detail in the general discussion.

Finally, reading times on the post-target word did not show a spillover effect of priming, suggesting that semantic relatedness did not continue to affect behavior once the eyes had left the target word. Instead, it appears that on fast trials, words were encoded sufficiently well to trigger a saccade to the next word before semantic relatedness information could exert an effect.

EXPERIMENT 2 – THE OCULAR LEXICAL DECISION TASK

The effect of priming in Experiment 1 followed the same distributional pattern as was found in the ocular LDT (Hoedemaker & Gordon, in press), supporting the idea that priming occurs by a shared mechanism across tasks. Nonetheless, the overall magnitude of the priming effect was substantially weaker in Experiment 1 than in Hoedemaker and Gordon, suggesting that at least some portion of the effect found in the LDT may be due task-specific decision processes. However, a direct comparison between the two studies is unwarranted, as Experiment 1 used different word pairs than Hoedemaker and Gordon, as well as a slightly different stimulus display. To assess the effect of task more carefully, the current experiment used the same stimulus display and a slightly reduced subset of the stimuli used in Experiment 1 in an ocular LDT. Consistent with the results of Hoedemaker and Gordon (in press), we expected that reading times in Experiment 2 would be slower than those in Experiment 1, but faster than manual LD response times for the same words in the ELP (Balota et al., 2007). Consistent with Hoedemaker and Gordon (in press), we expected to find a distributional effect of relatedness, such that the priming effect becomes increasingly stronger across the slow tail of the distribution. If at least a portion of the priming effect is specifically associated with the specific metalinguistic requirements of the LD task, we expect to see a larger priming effect in Experiment 2 compared to Experiment 1, independent of baseline response speed. As discussed previously, Thomas et al. (2012) have argued that τ-based priming observed for LDT depends crucially on the availability of backward (target to prime) associative connections. If so, we expect to see larger priming effects for prime-target pairs with strong backward association values. Such an effect was not found in Experiment 1, but the meta-linguistic requirement of the LD and slower baseline response times may cause backward associative relationships to have a larger effect on LDs compared to word reading times during the recognition task.

Method

Participants. A total of 33 undergraduate students from the University of North Carolina at Chapel Hill participated in the experiment for course credit. All participants were native speakers of English with normal or corrected-to-normal vision. One participant was excluded from all analyses because of high skipping rates (over 40% of trials included at least one skip), leaving a total of 32 subjects in the analysis.

Materials and design. A total of 120 experimental prime-target pairs were randomly selected from those used in Experiments 1. The experimental pairs consisted of 60 synonym or antonym pairs (30 of each), and 60 other-associates. For the selected pairs, the same unrelated prime-target pairings were maintained as those used in the other experiments. Two lists were constructed such that that each subject saw all targets, half preceded by a related prime and half preceded by an unrelated prime, and no words were repeated within a list. Each list was preceded by ten warm-up trials that were not included in the analysis.

A word or a nonword was added in the post-target position for each prime-target pair, so that half of the related and half of the unrelated pairs were followed by a nonword. For those pairs followed by a word in the third position, a word or nonword was added in the fourth and last position, distributed equally across related and unrelated trials. Filler trials were added so that on 20% of the trials (60 trials per list) a nonword appeared in the first (prime) position, and on 40% of the trials (120 trials per list) a filler word appeared in the first position followed by a nonword in the second (target position). As a result, there was always a .5 probability of a nonword appearing in the middle, third or fourth position given that the previous position contained a word. The filler words were the same as those used in the recognition experiments, supplemented by additional words from the Nelson et al. (1998) association database. A total of 270 nonwords were selected from the English Lexicon project (Balota et al., 2007). The experimental and filler words were equivalent in mean frequency, $F(1,446) = .56$, $p = .44$. The experimental words, fillers and nonwords were equivalent in word length, $F(2,715) = 1.54$, $p = .22$, and orthographic neighborhood size, $F(2,215) = 1.61$, $p = .20$.

Procedure. The equipment and procedure were very similar to those used in the recognition experiments, while the task was the same as the task used for Experiment 1 in Hoedemaker and Gordon (in press). At the beginning of each trial, a set of four masks appeared on the screen. Once fixated, each masked revealed a letter string according to the same gaze contingencies used in the other experiments. Participants were instructed to read the four words silently, and for each letter string decide whether it was a word or a nonword. Each time they decided a letter string was a word, they were to indicate this by moving their eyes as quickly as possible to the next letter string in the set. They were instructed to use a speeded key press on a hand-held console each time they decided the string was a nonword. This key press ended the trial. If they reached the fourth and last string in the set and judged it to be a word, they were instructed to move their eyes to a fixation point located to the right of the fourth word. In the case of a correct decision on the final word, the words “Correct! Please press the button to proceed to the next trial” appeared in response to fixating the final fixation point. The word ‘INCORRECT!’ was presented after an incorrect eye movement (i.e. making a forward saccade to the next letter string in cases where the currently fixated string was a nonword) or an incorrect button press (i.e., pressing the button while fixating a real word).

Analysis of eye movements. Eye movement measures for the prime, target and third-word position are reported. Fixations shorter than 80 ms and within 1 degree of a longer, immediately subsequent fixation were merged with the longer fixation by an automatic procedure in the EyeLink software. Trials on which either the prime or the target was skipped (7.7% of critical trials) were removed from the analyses, as were trials on which a boundary was inadvertently triggered due to a blink (.7% of critical trials) or because the eye fixated on or very near the boundary instead of on the word (5.2% of critical trials). The excluded trials were distributed equally across the related and unrelated conditions, with an average of 52 usable critical trials each condition. When brief delays in the display change caused a word to be unmasked slightly after the onset of the first fixation on a word, the timestamp of the fixation onset was adjusted to reflect the onset of the word display, excluding any time the participant was fixating the mask rather than the word; the adjustments averaged 7 ms (range 1 – 71 ms). Finally, a reading time cutoff was determined at three standard deviations above the mean for each position in the triplet in each relatedness condition. Gaze durations longer than the relevant cutoff were removed, affecting 1.8% of all words on critical trials, equally distributed across the related (1.7%) and unrelated (1.8%) trials.

Results

Mean accuracy across subjects on all (critical and filler) trials was 98% for words (range: 84% - 100%) and .86% for nonwords (range: .69 - .99). These levels of accuracy words and nonwords are similar to those found by the English Lexicon Project for these particular words (words: 97%, nonwords: 86%). Gaze durations across the prime, target and third-word position and relatedness condition are presented in Table 7. Mean gaze duration was 440 ms (sd = 63 ms) for unrelated words across all three positions (i.e., middle words in the related-prime condition were excluded). Average ocular LD times were significantly faster than manual LDs for the same words in the ELP (M = 635, sd = 68), t(299) = 56.98, $p < .001$. Mean gaze durations on individual words were correlated with manual response times in the ELP, r = .60, $R^2 = .36$ $p < .001$ (N = 300), but effect of SUBTLEX frequency (Brysbaert & New, 2009) on response times was greater for ocular LDs, r = -.60, $R^2 = .36$, $p < .001$ (N = 300) than manual LDs as observed in the ELP database, r = -.49, $R^2 = .24$ (N = 300), Fisher's z = 2.64, $p < .01$ (N = 300).

Table 7
Word reading times in Experiment 2. All times in are in milliseconds. Asterisks indicate a significant effect.

		Word Position		
Measure	Condition	Prime	Target	Post-Target
Word GZD (sd)	Related pairs	459 (89)	398 (77)	431 (82)
	Unrelated pairs	451 (82)	425 (79)	417 (71)
	Mean	455 (85)	411 (79)	424 (77)
	Priming	***-8***	***27****	***-14****
Word FFD (sd)	Related pairs	254 (68)	333 (66)	332 (70)
	Unrelated pairs	250 (59)	348 (67)	329 (63)
	Mean	252 (63)	341 (66)	330 (66)
	Priming	***-4***	***16****	***-3***
Word SFD (sd)	Related pairs	386 (86)	371 (73)	385 (74)
	Unrelated pairs	387 (83)	395 (79)	377 (68)
	Mean	386 (84)	383 (76)	381 (71)
	Priming	***1***	***24****	***-8***
Proportion Single Fixation Trials (sd)	Related pairs	.34 (.19)	.70 (.20)	.58 (.22)
	Unrelated pairs	.33 (.18)	.67 (.21)	.62 (.20)
	Mean	.33 (.18)	.68 (.20)	.60 (.21)
	Priming	***-.01***	***-.03***	***.04***

Associative relatedness. Target word reading times showed a significant effect of relatedness, such that ocular LDs for targets were faster in the related compared to the unrelated condition across all eye movement measures, GZD: $t_1(31) = 4.48$, $p < .001$, $t_2(119) = 6.71$, $p <$

.001, SFD: $t_1(31) = 4.18$, $p < .001$, $t_2(119) = 4.94$, $p < .001$; FFD: $t_1(31) = 3.40$, $p < .01$, $t_2(119) = 4.03$, $p < .001$.Gaze durations on the post-target word showed a reversed effect of prime-target relatedness, such that post-target reading times were longer after a related compared to an unrelated prime-target pair, $t_1(31) = -2.43$, $p < .05$, $t_2(59) = -2.06$, $p < .05$. However, this effect was not significant for single-fixation duration, $t_1(31) = -1.45$, $p = .16$, $t_2(59) = -.78$, $p = .44$, or first-fixation duration, $t_1(31) = -.45$, $p = .66$, $t_2(59) = -.52$, $p =.61$.

Multilevel model analysis. Target and post-target word reading times were also assessed using multi-level models (MLMs). All models were built according to the same procedure used in Experiment 1. Results of the control models are presented in Tables 8 and 9, the random effect structure is presented in Tables 10 and 11and the coefficients, standard errors and t-values for each predictor are presented in Tables 12, and 13. Significance levels did not change for any of the predictors when the models were rerun without non-significant interactions between the predictors of interest.

The results of the MLM analyses are largely consistent with the ANOVAs. Target word reading times showed an effect of relatedness on all eye movement measures, such that related targets were read more quickly than unrelated targets. Gaze duration and first-fixation duration showed a main effect of forward association strength, such that targets in highly associated pairs were read more quickly than targets in weakly associated pairs. In addition, for single-fixation duration and first fixation duration the effect of relatedness varied as a function of forward association strength, such that more strongly associated pairs showed greater priming for these measures. For single-fixation duration, the effect of relatedness for prime target pairs with low (1 standard deviation below the mean FAS value in this stimulus set), medium (average FAS value in the stimulus set), and high FAS (1 standard deviation above the mean FAS values in the stimulus set) were estimated to be 16, 24, and 32 ms respectively. For first-fixation duration, the relatedness effect was estimated at 8 (low FAS), 17 (medium FAS) and 26 (High FAS). Backward association strength and SPP priming score did not have a significant effect on target word reading times.

Post-target word reading times showed an effect of relatedness in the opposite direction from the target words, so that post-targets words following a related prime-target pair were read more slowly than following an unrelated prime target pair. Forward association strength, backward association strength and SPP priming score did not have a significant effect on post-target word reading times.

Table 8
T-values for control variables included in the MLM for the target word in Experiment 2. Dashes indicate the control variable was not significant in the control model and excluded from the full model.

	Measure		
Variable	GZD	SFD	FFD
Frequency Prime	3.88	5.42	3.97
Frequency Target	-7.72	-7.07	-3.55
GZD Prime	12.89	12.34	11.83
Trial Number	-6.24	-2.77	4.47

Table 9
T-values for control variables included in the MLM for the post-target word in Experiment 2. Dashes indicate the control variable was not significant in the control model and excluded from the full model.

	Measure		
Variable	GZD	SFD	FFD
Frequency Target	2.43	3.22	4.03
Frequency Post-Target	-7.14	-4.57	-2.31
GZD Target	6.55	9.18	7.52
Trial Number	-5.50	--	3.07

Table 10

Random slopes included in the MLM for the target word in Experiment 2. Dashes indicate the random slope was not included in the full model. Asterisks indicate the slope was included in the full model.

	Measure		
Slope	GZD	SFD	FFD
Priming by subjects	*	*	*
Priming by items	-	-	-

Table 11

Random slopes included in the MLM for the post-target word in Experiment 2. Dashes indicate the random slope was not included in the full model. Asterisks indicate the slope was included in the full model.

	Measure		
Slope	GZD	SFD	FFD
Priming by subjects	*	-	*
Priming by items	-	-	-

Table 12

Results of the MLM for the target word in Experiment 2. Significant t-values are presented in bold.

	Measure								
	GZD			SFD			FFD		
Main Effects	***b***	**SE**	**t**	***b***	**SE**	**t**	***b***	**SE**	**t**
Related	-31.06	5.35	**-5.80**	-23.95	4.51	**-5.31**	-17.30	4.48	**-3.86**
FAS	-60.00	15.77	**-3.37**	-27.14	14.86	-1.83	-31.25	14.91	**-2.10**
BAS	16.29	15.77	1.03	8.33	13.65	.61	22.22	13.80	1.61
SPP Priming	15.94	15.55	1.03	24.40	13.55	1.80	9.20	13.49	.68
Interactions	***b***	**SE**	**t**	***b***	**SE**	**t**	***b***	**SE**	**t**
Related*FAS	-32.32	21.45	-1.51	-47.09	22.66	**-2.08**	-53.61	21.89	**-2.45**
Related*BAS	-16.16	18.50	-.87	-6.50	19.21	-.34	-9.94	18.90	-.53
Related*SPP	7.419	19.44	.38	28.01	20.82	1.35	-1.41	19.83	-.07

Table 13
Results of the MLM for the post-target word in Experiment 2. Significant t-values are presented in bold.

	Measure								
	GZD			SFD			FFD		
Main Effects	***b***	**SE**	**t**	***b***	**SE**	**t**	***b***	**SE**	**t**
Related	21.51	5.87	**3.66**	18.73	5.84	**3.21**	9.89	5.82	1.70
FAS	23.95	27.37	.88	12.68	27.08	.47	16.48	19.36	.85
BAS	5.15	52.09	.22	-4.35	22.64	-.19	-1.57	16.46	-.10
SPP Priming	-21.11	27.07	-.78	-19.57	26.62	-.74	-9.02	19.271	-.47
Interactions	***b***	**SE**	**t**	***b***	**SE**	**t**	***b***	**SE**	**t**
Related*FAS	-.30	32.61	-.01	-45.57	34.27	-1.33	-46.32	32.26	-1.44
Related*BAS	3.63	27.26	.13	4.03	27.66	.15	37.41	26.99	1.39
Related*SPP	21.52	31.09	.69	15.00	32.66	.46	16.22	30.75	.53

Ex-Gaussian distribution fit. Ex-Gaussian distributions were fit in the same manner as for Experiment 1. Two participants were excluded from the analyses because their RT distribution did not fit the typical ex-Gaussian pattern and resulted in outlying values on the distributional parameter estimates. The quantile estimates for gaze duration, single-fixation duration and first-fixation duration are plotted in Figure 5. Naturally, reading times increased across quantiles for all three measures: GZD: $F(1,29) = 236.33$, $p < .001$, SFD: $F(1,28) = 105.30$, $p < .001$, FFD: $F(1,28) = 164.25$, $p < .001$. In addition, all measures showed a significant main effect of relatedness, $F(1,29) = 29.36$, $p < .001$, SFD: $F(1,28) = 26.12$, $p < .001$, FFD: $F(1,29) = 10.10$, $p < .01$. There was also a significant interaction between quantile and relatedness, indicating that the effect of relatedness increased across the slow tail of the distribution, as can also be observed from the quantile plots, : GZD: $F(1,29) = 10.20$, $p < .001$, SFD: $F(1,28) = 5.24$, $p < .05$, FFD: $F(1,29) = 13.73$, $p < .001$. These results remained the same regardless of 10^{th}-quantile inclusion, except for single-fixation duration which no longer showed a significant relatedness by quantile interaction when the 10^{th} quantile was excluded, $F(1,28) = 2.73$, $p = .11$.

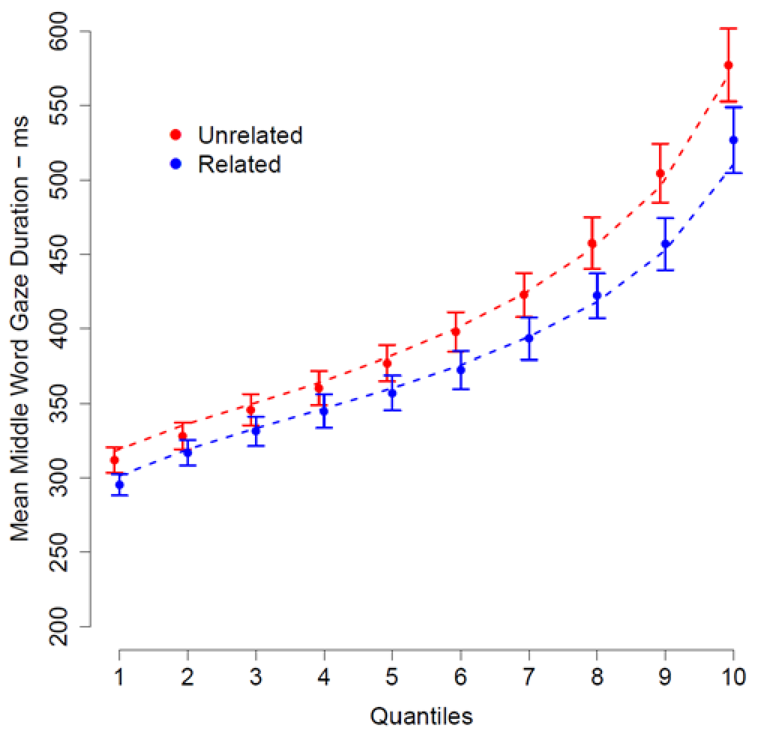
Average ex-Gaussian parameter estimates for gaze duration and first-fixation duration are shown in Table 14. Single-fixation duration did not yield a large enough number of observations to allow for ex-Gaussian distribution fits. There was no effect of relatedness on μ, GZD: t(29) = 1.05, p = .30, FFD: t(29) = -1.93, p = .06, or σ, GZD: t(29) = -1.43, p = .16, FFD: t(29) = -.59, p = .56. Estimates of τ showed a significant effect of relatedness on both measures, indicating an increase in priming across the slow tail of the distribution, GZD: t(29) = 2.35, $p < .05$, FFD: t(29) = 3.39, $p < .01$.

Table 14
Ex-Gaussian parameter estimates in Experiment 2. All times are in milliseconds. Asterisks indicate a significant effect.

		Parameter		
Measure	Condition	Mu	Sigma	Tau
GZD (sd)	Related	307 (58)	29 (26)	83 (39)
	Unrelated	314 (52)	22 (22)	105 (50)
	Priming	***7***	***-6***	***22****
FFD (sd)	Related	277 (64)	53 (34)	51 (44)
	Unrelated	267 (60)	50 (31)	78 (61)
	Priming	***-10***	***-3***	***27****

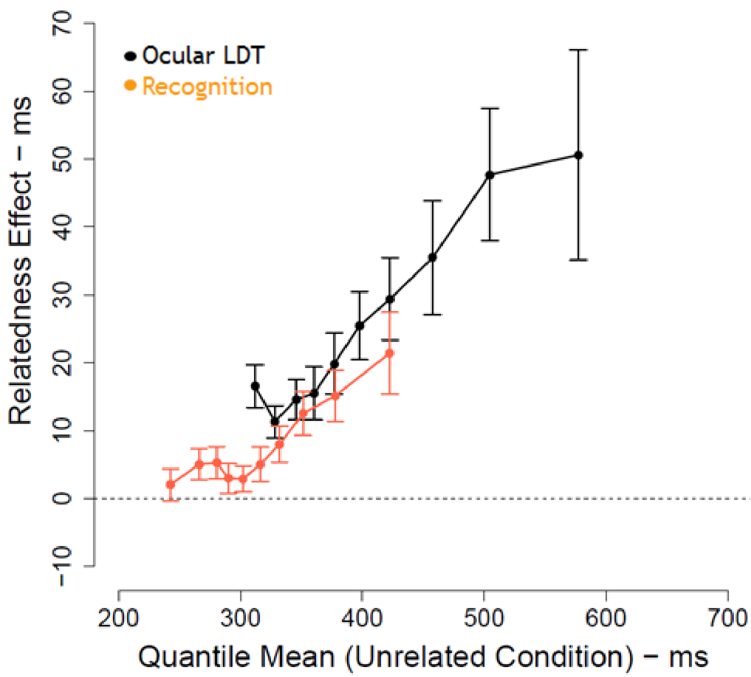
Figure 5

Quantile plot for mean gaze durations on the middle word in the ocular lexical decision task (Experiment 2) when the target was preceded by a related or an unrelated prime. Quantile estimates were calculated by ranking RTs for each participant in each condition from fastest to slowest, and dividing them into 11 equally spaced bins. Ten observed quantile estimates were then generated by taking the average of the slowest trial in one bin and the fastest trial in the next bin. Quantiles are arranged from fastest to slowest on the x-axis. Error bars show the standard error of the quantile value across subjects and the dashed lines represent predicted quantile values based on mean parameters of the estimated ex-Gaussian distribution.



Comparing priming across ocular LDT and recognition tasks. Figure 6 shows the priming effects in Experiment 1 (recognition) and 2 (ocular LDT) as a function of the baseline RT (average response time in the unrelated condition. The plot shows that response times in the LDT are slower than those in the ocular recognition task, and on average the priming effect is larger in the LDT. However, in both experiments the magnitude of the priming effect increases as a function of response time. Moreover, for those portions of the distribution where the response times in the recognition and LD tasks are approximately equal, the effect of priming is of similar magnitude across both experiments, and appears to increase at a similar rate. Together, these results suggest that the priming effect in the ocular LDT does not differ from the priming effect in the recognition task, at least for responses faster than 422 ms (the average response time in the slowest bin of the recognition task).

Figure 6
Mean priming effect (gaze duration in the unrelated – related condition) by baseline response speed (average gaze duration in the unrelated condition) in the ocular recognition task (Experiment 1) and the ocular lexical decision task (LDT, Experiment 2).



Discussion

The results of Experiment 2 replicate those found by Hoedemaker and Gordon (in press). Ocular LDs showed a robust effect of relatedness, and the priming was concentrated in the slow tail of the distribution. Based on the quantile plots, there appeared to be a larger priming effect in the fastest bins of the distribution than was found in Hoedemaker and Gordon, and there was some evidence that the magnitude of the priming effect was greater for pairs with stronger forward association. Taken together, these results suggest that there may have been some influence of a prospective priming effect, but in the absence of a significant effect on estimates of μ we cannot draw strong conclusions on this topic.

Average word reading times were slower in the current experiment compared to Experiment 1, suggesting that at least a portion of LD response times is dedicated to LDT-specific processing. However, when baseline response time was held constant (i.e., for those overlapping RT distributions in Figure 6), the priming effect was of similar magnitude across tasks, and appeared to increase at a similar rate. While ex-Gaussian parameters cannot be mapped directly onto cognitive processes (Balota & Yap, 2011; Matzke & Wagenmakers, 2009), the current pattern of results does not provide evidence that priming in the lexical decision task is the result of an LD-specific processing mechanism operating specifically in service of the word-nonword decision, as has been suggested by De Wit and Kinoshita (2014, 2015) and Balota and colleagues (Balota et al., 2008; Yap et al., 2012). Instead, the magnitude of the priming effect appears to depend more heavily on baseline response times than on the task-specific processing goals of the reader.

Further, contrary to Thomas et al. (2012)'s findings, we did not find evidence that retrospective priming was dependent on the strength of backward associative connections. As discussed in relation to Experiment 1, this finding is inconsistent with an interpretation of τ-based priming as reflecting a goal-driven retrospective priming process such that participants are actively 'thinking back' to the previously processes prime. Instead, it appears that information about the prime-target relationship (whether forward/backward associated or based on feature-based similarity) becomes activated relatively slowly. As a result, fast target responses do not show a large influence of the prime, but slow, more effortful responses do.

EXPERIMENT 3 – OCULAR RECOGNITION MEMORY WITH ORTHOGRAPHICALLY SIMILAR FOILS

The magnitude of the priming effect increased across the slow tail of the distribution both during the ocular LDT (Experiment 2) and the recognition memory task (Experiment 1), suggesting that retrospective priming took place regardless of task. In both tasks, prime information appeared to have a greater influence when word recognition was more effortful, whether this effort is due to a meta-linguistic lexical decision (Experiment 2) or inherent difficulties in lexical encoding (Experiment 1). However, lexical decisions in Experiment 2 were much slower than word reading times in Experiment 1, thereby confounding the effects of task and response speed. Experiment 3 sets out to dissociate the effects of task and speed by slowing down word reading times in the recognition task without changing the explicit task goals. Word encoding difficulty was increased by using orthographically similar foils as 'new' memory probe words. For example, in Experiment 1, the trial containing the stimulus set *small – little – ring – dog* is followed by the new, orthographically dissimilar probe *faith.* In Experiment 3, the same trial will be followed by new probe *rinse* which is orthographically similar to the third word *ring* in the stimulus set. If greater word recognition difficulty universally increases retrospective priming, we should see greater priming in the current experiment compared to Experiment 1, specifically in the slow tail of the distribution. Alternatively, the magnitude of the priming effect may be task specific. The orthographically similar foils likely encourage greater allocation of attention to the orthographic rather than semantic characteristics of the words, and target word encoding difficulty at the orthographic level may be less likely to trigger if not benefit from retrospective recruitment of a related prime word. If priming is related to specific processing goals of the reader, in particular processing goals that may benefit from semantic information, the current experiment should show smaller priming effects compared to Experiment 1, both in the comparison of means and in the degree to which the effect of priming is concentrated in the slow tail of the distribution.

Method

Participants. A total of 59 undergraduate students from the University of North Carolina at Chapel Hill participated in the experiment for course credit. All participants were native speakers of English with normal or corrected-to-normal vision. Eight participants were excluded from all analyses because of high skipping rates (on over 40% of trials included at least one skip), leaving a total of 51 subjects in the analysis. After 32 participants had been tested, the overall error rate in Experiment 3 was found to be higher than in Experiment 1. Additional subjects were tested in order to allow selection of participants with accuracy rates matching the overall accuracy of Experiment 1. Data for the current experiment will be reported for the subset of 30 participants with the highest accuracy scores, a selection that equates both the total number of participants and average accuracy between 1 and 3.

Materials and design. The stimuli in Experiment 3 were the same as those in 1 except for the foil ('new') probes. In contrast to Experiment 1, foil probes in the current experiment were selected to be orthographically similar to one member of the recognition set for a respective trial. For example, in Experiment 1 the trial containing stimulus set *small – little – ring – dog* was followed by the new, orthographically dissimilar probe *faith.* In Experiment 3, the same trial was be followed by new probe *rinse* which is orthographically similar to the third word *ring* in the stimulus set. Orthographically similar foils were selected so that they resembled the stimulus words from each of the four positions equally often. Within each list, the old and foil probes did not differ significantly by frequency, List 1: t(158) = 1.54, p = .13, List 2:(158) = 1.45, p = .15, length: List 1: t(158) = 1.30, p = .19, List 2: t(158) = 1.62, p = .11, and orthographic neighborhood size, List 1: t(158) = 1.54, p = .13, List 2: (158) = 1.91, p = .06.

Procedure. The procedure was identical to Experiment 1.

Analysis of eye movements. Eye movement measures for the prime, target and third-word position are reported; the fourth word required a key-press response. Fixations shorter than 80 ms and within 1 degree of a longer, immediately subsequent fixation were merged with the longer fixation by an automatic procedure in the EyeLink software. Trials on which either the prime or the target was skipped (8.7% of trials) were removed from the analyses, as were trials on which a boundary was inadvertently triggered due to a blink (1.1 % of trials) or because the eye fixated on or very near the boundary instead of on the word (7.2% of trials). Finally, trials on which the participant regressed from the target back to the (then masked) prime rather than progressing to the post-target word were also removed (.2% of trials). The excluded trials were distributed equally across the related and unrelated conditions, with an average of 66 and 67 usable trials respectively remaining in each condition. When brief delays in the display change caused a word to be unmasked slightly after the onset of the first fixation on a word, the timestamp of the fixation onset was adjusted to reflect the onset of the word display, excluding any time the participant was fixating the mask rather than the word; the adjustments averaged 5 ms (range 1 – 90 ms). Finally, a reading time cutoff was determined at three standard deviations above the mean for each position in the triplet in each relatedness condition. Gaze durations longer than the relevant cutoff were removed, affecting 2.3% of all words, equally distributed across the related (2.3%) and unrelated (2.4%) trials.

Results

While the critical results of this study pertain to semantic priming, the general characteristics of performance are first reviewed and compared to those of Experiment 1 in order to establish the effect across experiments of changing from dissimilar to similar foils.

Mean accuracy across all 51 subjects was 96% (sd = 1.7%, range: 89% - 100%). Overall accuracy in 3 was significantly lower than in 1, t(79) = 4.27, $p < .001$. For the 30 participants in 3 with the highest accuracy rate, average accuracy was 98% (range: 96% - 100%). For the selected participants in the high-accuracy subset, average accuracy did not differ significantly between 1 and 3, t(58) = 1.29, $p = .21$. To facilitate comparison between Experiment 1 and 3, only the results for the subset of high accuracy participants in Experiment 3 are presented here.

Gaze durations across the prime, target and third-word position and association condition are presented in Table 15. Mean gaze duration was 385 ms (sd = 40 ms) for unrelated words across all three positions (i.e., middle words in the related-prime condition were excluded). Average gaze duration was significantly slower for the similar foils (Experiment 3) compared to the dissimilar foils (Experiment 1), $t_1(58) = -3.09$, $p < .01$, $t_2(478) = -28.54$, $p < .001$. Mean gaze durations on individual words were correlated with manual response times in the ELP, r = .42, R^2 = .17 $p < .001$ (N = 477), and negatively correlated with SUBTLEX (Brysbaert & New, 2009) log word frequency, r = -.38, $R^2 = .15$, $p < .001$ (N = 480). There was no significant difference in the magnitude of the frequency effect for similar foils (3) compared to dissimilar foils (1), z = 1.39, $p = .17$. However, gaze duration in the current experiment (similar foils) showed a significantly greater effect of word length. A 2 (dissimilar foils (Exp 1) vs similar foils (Exp 3)) by 7 (Word length: 4, 5 , 6, 7, 8, 9, or >9 letters) by-items ANOVA showed a general increase in gaze duration for longer words, $F_1(1,58) = 77.59$ $p < .001$, $F_2(6, 472) = 26.30$, $p < .001$,but this effect was modified by experiment, $F_1(1,58) = 8.56$, $p < .001$, $F_2(6, 472) = 5.65$, $p < .001$, such that the effect of word length caused a steeper increase in gaze durations for the experiment with similar foils (Exp 3) than in the experiment with dissimilar foils (Exp 1).

Table 15
Word reading times in Experiment 3. All times are in milliseconds. Asterisks indicate a significant effect.

		Word Position		
Measure	Condition	Prime	Target	Post-Target
Word GZD (sd)	Related pairs	394 (113)	364 (73)	396 (73)
	Unrelated pairs	391 (108)	373 (83)	405 (78)
	Mean	392 (109	369 (78)	400 (75)
	Priming	***-3***	***9****	***9****
Word FFD (sd)	Related pairs	257 (44)	292 (41)	293 (43)
	Unrelated pairs	262 (50)	293 (40)	297 (40)
	Mean	260 (47)	292 (40)	295 (41)
	Priming	***5***	***1***	***4***
Word SFD (sd)	Related pairs	334 (94)	328 (57)	336 (50)
	Unrelated pairs	336 (97)	329 (56)	345 (51)
	Mean	335 (95)	329 (56)	341 (51)
	Priming	***2***	***1***	***9***
Proportion Single Fixation Trials (sd)	Related pairs	.47 (.20)	.66 (.20)	.58 (.25)
	Unrelated pairs	.49 (.21)	.66 (.21)	.58 (.25)
	Mean	.48 (.21)	.66 (.20)	.58 (.25)
	Priming	***.02***	***0***	***0***

Associative relatedness and semantic relationship types. Table 16 shows the mean reading times for the target words across relatedness condition for synonym/antonym pairs and other-associate pairs. The was a main effect of relatedness on gaze duration, so that target words were read more quickly in the related compared to the unrelated condition, $F_1(1,29) = 12.64$, $p < .01$, $F_2(1,158) = 5.82$, $p < .05$. This effect was not significant for any of the other eye movement measures, Fs < 1. Gaze duration showed a main effect of relationship type, $F_1(1,29) = 5.88$, $p < .01$, $F_2(1,158) = 4.83$, $p < .05$, such that otherwise associated targets were read more slowly than synonym/antonym targets. The same effect was observed for single-fixation duration, although the effect did not reach significance in the by-items analysis, $F_1(1,29) = 4.80$, $p < .05$, $F_2(1,158) = 2.49$, $p = .12$, for first-fixation duration in the by-subjects analysis, $F_1(1,29) = 4.31$, $p < .05$, $F_2(1,158) = 2.17$, $p = .14$. The effect of relatedness did not differ as a function of relatedness type for gaze duration, $F_1(1,29) = .90$, $p = .35$, $F_2(1,158) = .21$, $p = .65$, single fixation duration, $F_1(1,29) = .11$, $p = .75$, $F_2(1,158) = .10$, $p = .75$, first-fixation duration, $F_1(1,29) = .06$, $p = .81$, $F_2(1,158) = .02$, $p = .88$.

In contrast to Experiment 1, there was some evidence in Experiment 3 that target-word manipulations caused effects to spill over on fixation durations measures on the third, post-target word. Gaze duration on the post-target word showed an effect of relatedness (although marginal in the by-items analysis), $F_1(1,29) = 6.34$, $p < .05$, $F_2(1,158) = 3.63$, $p = .06$, such that reading times were shorter after a related compared to an unrelated target. The same effect was marginal by subjects for single-fixation duration, $F_1(1,29) = 3.28$, $p = .08$; $F_2(1,158) = 1.71$ $p = .19$, but not significant for first-fixation duration, $F(1,29) = 2.03$, $p = .17$,$F(1,158) = 2.26$, $p = .14$. Gaze duration on the third-word showed an effect of relationship type that was consistent with the pattern of results on the target word, $F_1(1,29) = 4.14$, $p = .05$, $F_2(1,158) = .4.83$, $p < .05$, such that post-target words following otherwise associated pairs were read more slowly than synonym/antonym targets. This effect was not significant for single-fixation duration, $F_1(1,29) = 2.5$, $p = .13$, $F_2(1,158) = .15$, $p = .70$, or first-fixation duration, Fs < 1. The effect of relatedness did not differ as a function of relationship type for any of the eye movement measures on the post-target word, Fs < 1.6.

Table 16
Target word reading times by relationship type across the related and unrelated condition in Experiment 3. All times are in milliseconds.

Measure	Condition	Relationship Type	
		Synonyms/Antonyms	Associated
GZD (sd)	Related	360 (72)	366 (75)
	Unrelated	366 (76)	381 (94)
	Mean	363 (74)	374 (85)
	Priming	***6***	***15***
FFD (sd)	Related	289 (40)	294 (43)
	Unrelated	289 (36)	296 (47)
	Mean	289 (38)	295 (45)
	Priming	***0***	***2***
SFD (sd)	Related	323 (55)	333 (61)
	Unrelated	324 (50)	337 (74)
	Mean	323 (51)	335 (67)
	Priming	***1***	***4***
Proportion Single-Fixation Trials (sd)	Related	.67 (.18)	.66 (.22)
	Unrelated	.67 (.21)	.64 (.23)
	Mean	.67 (.19)	.65 (.22)
	Priming	***0***	***-.02***

Multilevel model analysis. Similar to Experiment 1, the effects of interest occasionally yielded results that were not fully consistent between the by-subjects and by-items analyses. Therefore, target and post-target word reading times were also assessed using multi-level models (MLMs). All models were built in the same way as in Experiment 1 and 2. Results of the control models are presented in Table 17 and 18, and the random effect structure for each model is presented in Table 19 and 20. Significance levels did not change for any of the predictors when the models were rerun without non-significant interactions between the predictors of interest.

The results of the MLM analyses (Table 21) are largely consistent with the ANOVAs. There was a main effect of relatedness on gaze duration, but not on any of the other measures. Type of relationship did not have a significant effect on any of the measures, and the effect of relatedness did not vary as a function of relationship type. Forward association strength, backward association strength and SPP priming score did not have significant effects on reading times and did not interact with relatedness. Whereas the ANOVA showed a significant spillover effect of relatedness on gaze duration for the post-target word, the MLM did now yield a significant effect for any of the predictors (see Table 22).

Table 17
T-values for the control variables included in the MLM for the target word in Experiment 3. Dashes indicate the variable was not significant in the control model and excluded from the model.

	Measure		
Variable	GZD	SFD	FFD
Frequency Prime	--	--	--
Frequency Target	5.35	-2.71	--
GZD Prime	24.74	19.80	15.95
Trial Number	-9.26	-6.42	--

Table 18
T-values for the control variables included in the MLM for the post-target word in Experiment 3. Dashes indicate the variable was not significant in the control model and excluded from the model.

	Measure		
Variable	GZD	SFD	FFD
Frequency Target	-	-	-
Frequency Third	-5.47	-4.23	-
GZD Target	14.52	11.14	9.16
Trial Number	-14.38	-9.50	-3.19

Table 19
Random slopes included in the MLM for the target word in Experiment 3. Dashes indicate the random slope was not included in the full model. Asterisks indicate the slope was included in the full model.

	Measure		
Slope	GZD	SFD	FFD
Priming by subjects	-	-	-
Priming by items	-	-	-

Table 20

Random slopes included in the MLM for the post-target word in Experiment 3. Dashes indicate the random slope was not included in the full model. Asterisks indicate the slope was included in the full model.

	Measure		
Slope	GZD	SFD	FFD
Priming by subjects	-	-	*
Priming by items	-	-	-

Table 21

Results of the MLM for the target word in Experiment 3. Rel.Type = Relationship Type. Significant t-values are presented in bold.

	Measure								
	GZD			SFD			FFD		
Main effects	***b***	**SE**	**t**	***b***	**SE**	**t**	***b***	**SE**	**t**
Related	-12.30	3.04	**-4.05**	-4.38	2.77	-1.58	-2.60	2.74	-0.95
Relationship Type	3.47	3.84	0.90	4.02	3.62	1.11	1.60	3.31	0.48
FAS	-18.43	10.80	-1.71	9.17	10.24	0.90	13.70	9.54	1.44
BAS	12.88	9.57	1.35	6.51	8.97	0.73	0.44	8.39	0.05
SPP Priming	-14.66	9.58	-1.53	-3.79	9.04	-0.42	0.67	8.44	0.08
Interactions	***b***	**SE**	**t**	***b***	**SE**	**t**	***b***	**SE**	**t**
Related*Rel.Type	-9.41	6.10	-1.54	-4.64	5.54	-0.84	0.16	5.51	0.03
Related*FAS	-8.35	17.58	-0.48	-13.40	16.04	-0.84	-21.02	15.88	-1.32
Related*BAS	3.19	15.41	0.21	4.13	13.79	0.30	.29	13.92	-0.09
Related*SPP	-14.48	15.60	-0.93	-9.03	14.15	-0.64	-13.92	14.08	-0.99

Table 22
Results of the MLM for the post-target word in Experiment 3. Rel.Type = Relationship Type. Significant t-values are presented in bold.

	Measure								
	GZD			SFD			FFD		
Main Effects	***b***	**SE**	**t**	***b***	**SE**	**t**	***b***	**SE**	**t**
Related	-6.11	3.74	-1.64	-3.92	3.42	-1.15	-2.63	3.11	-0.85
Relationship Type	-5.75	4.73	-1.22	-1.53	3.87	-0.40	-0.56	3.29	-0.17
FAS	0.61	13.47	0.05	1.11	10.88	0.10	15.85	9.47	1.68
BAS	6.83	11.85	0.58	11.01	9.73	1.13	2.93	8.31	0.35
SPP Priming	3.04	11.91	0.25	-5.01	9.74	-0.51	-1.03	8.37	-0.12
Interactions	***b***	**SE**	**t**	***b***	**SE**	**t**	***b***	**SE**	**t**
Related*Rel.Type	0.46	7.50	0.06	-5.361	6.85	-0.78	-6.30	5.90	-1.07
Related*FAS	24.45	21.62	1.13	23.74	19.29	1.23	2.70	17.01	0.16
Related*BAS	4.37	18.95	0.23	-0.27	17.27	-1.17	-17.46	14.91	-1.17
Related*SPP	-4.02	19.13	-0.21	31.47	17.29	1.82	16.08	15.05	1.07

Ex-Gaussian distribution fit. Ex-Gaussian distributions were fit in the same manner as for Experiment 1 and 2. One participant was excluded from the analyses because his or her RT distribution did not fit the typical ex-Gaussian pattern and resulted in outlying values on the distributional parameter estimates. The means analyses reported above were rerun without this subject and all of the effects of interest remained unchanged.

The quantile estimates for gaze duration, single-fixation duration and first-fixation duration are plotted in Figure 7. Naturally, reading times increased across quantiles for all three measures: GZD: $F(1,28) = 104.45$, $p < .001$, SFD: $F(1,22) = 119.65$, $p < .001$, FFD: $F(1,28) = 212.55$, $p < .001$. In addition, gaze duration showed a significant main effect of relatedness, $F(1, 28) = 6.66$, $p < .05$, but this effect was not observed for first-fixation duration, $F(1, 28) = .076$, $p = .79$, or single-fixation duration, $F(1,22) = .142$, $p = .71$. Gaze duration showed a marginal interaction between quantile and relatedness, $F(1,28) = 3.52$, $p = .07$ suggesting that the effect of relatedness increased across slower RTs, as can also be observed from the quantile plots. However, this effect was not observed for single-fixation duration, $F(1,22) = .65$, $p = .43$, or first-fixation duration, F(1,28) = 1.70, p = .20. Moreover, the quantile by relatedness interaction was no longer significant when the 10^{th} and final quantile was excluded from analysis, GZD: F(1,28) = 2.13, p = .16, SFD: F(1,22) = 1.48, p = .24, FFD: F(1,28) = .80, p = .38, suggesting these effects depended primarily on the slowest 10^{th} quantile.

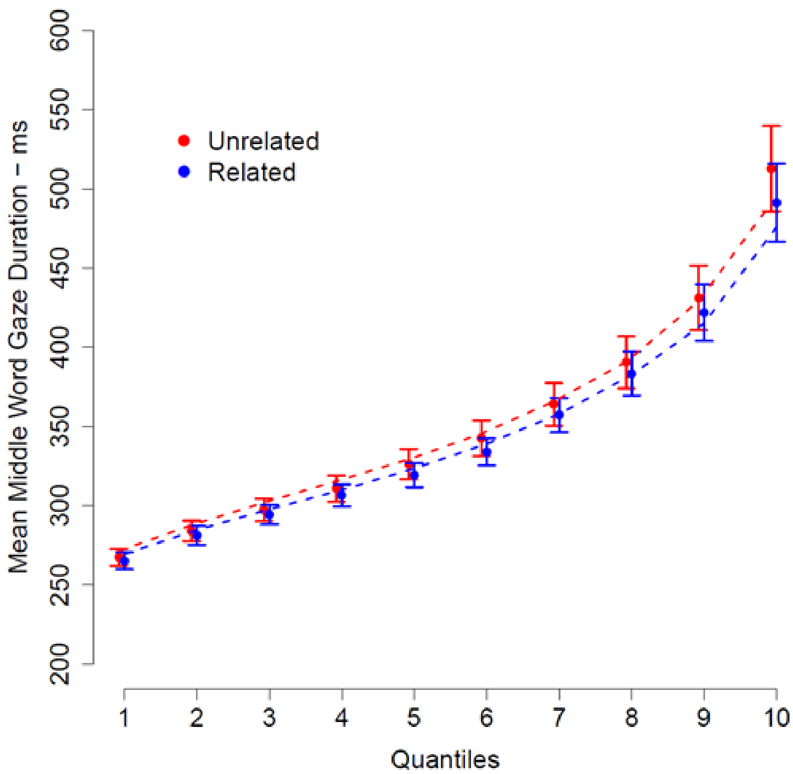
Average ex-Gaussian parameter estimates are shown in Table 23. There was no effect of relatedness on estimates of μ for gaze duration, single-fixation duration, or first-fixation duration, all ts < 1. Similarly, there were no effects of relatedness on σ, all ts < 1, and no effects or relatedness on τ for gaze duration, t(28) = 1.22, p = .23, single-fixation duration, t < 1 or first-fixation duration, t < 1.

Table 23
Ex-Gaussian parameter estimates in Experiment 3. All times are in milliseconds. Asterisks indicate a significant effect.

		Parameter		
Measure	Condition	Mu	Sigma	Tau
GZD (sd)	Related	269 (31)	23 (11)	84 (51)
	Unrelated	272 (32)	25 (21)	89 (53)
	Priming	***3***	***2***	***5***
FFD (sd)	Related	246 (44)	46 (24)	39 (41)
	Unrelated	250 (33)	49 (24)	35 (32)
	Priming	***4***	***3***	***-4***
SFD (sd)	Related	267 (29)	24 (8)	49 (31)
	Unrelated	265 (26)	22 (13)	51 (32)
	Priming	***-2***	***-2***	***3***

Figure 7

Quantile plot for mean gaze durations on the middle word in the ocular recognition task with orthographically similar foils (Experiment 3) when the target was preceded by a related or an unrelated prime. Quantile estimates were calculated by ranking RTs for each participant in each condition from fastest to slowest, and dividing them into 11 equally spaced bins. Ten observed quantile estimates were then generated by taking the average of the slowest trial in one bin and the fastest trial in the next bin. Quantiles are arranged from fastest to slowest on the x-axis. Error bars show the standard error of the quantile value across subjects and the dashed lines represent predicted quantile values based on mean parameters of the estimated ex-Gaussian distribution.



Effects of foil similarity. To assess the effect of foil similarity, we compared the distributional effects of relatedness across Experiment 1 (dissimilar foils) and 3 (similar foils). Unless otherwise mentioned, all results are the same for analysis including and excluding the 10^{th} quantile. Of course, the effect of quantile was significant across all three measures, GZD: F(1,56) = 244.97, p < .001, SFD: F(1,49) = 313.43.26, p < .001, FFD: F(1,56) = 450.53, p < .001. More importantly, the quantile analysis showed a main effect of foil type, F(1,56) = 5.82, p < .02 on gaze duration, reflecting a general slowing of reading times when the foil probes were orthographically similar to the stimulus words (Experiment 3). This effect was marginal for single-fixation duration, $F(1, 56) = 4.04$, $p = .05$, but not significant for first-fixation duration, $F(1, 56) = .69$, $p = .41$. Gaze duration showed a significant interaction between quantile and experiment, GZD: $F(1, 56) = 5.92$, $p <.05$, indicating a general slowing as indicated by the main effect of foil similarity, as well as a steeper increase in reading times across the distribution when the foils were orthographically similar (i.e., greater rightward skew). This effect was marginal for first-fixation duration, $F(1, 56) = 3.34$, $p =.07$, but not significant for single-fixation duration, $F(1,49) = .79$, $p =.41$.

Figure 8 shows the priming effects on gaze duration in Experiment 1 (dissimilar foils) and 3 (similar foils) as a function of the baseline RT (average response time in the unrelated condition). Across foil types, gaze duration showed a main effect of relatedness, $F(1, 56) = 18.58$, $p < .001$, but this effect was not significant for first-fixation duration, $F(1, 56) = .51$, $p = .48$, or single-fixation duration, $F(1, 49) = 2.07$, $p = .16$. In addition, the effect of relatedness did not vary as a function of experiment, suggesting that the magnitude of the priming effect was the same across the similar and dissimilar foils, all $Fs < 1$. As in the individual experiments, there was a significant interaction between relatedness and quantile for gaze duration, $F(1,56) = 13.04$, $p < .01$, and this effect was marginal for single-fixation duration, $F(1,49) = 3.22$, $p = .08$, such that the effect of relatedness increases for slower trials. However, the interaction effect on single-fixation duration was no longer significant when the slowest quantile was excluded, $F(1,49) = .01$, $p = .94$, and the interaction was not significant for first-fixation duration, $F(1,56) = .70$, $p = .41$. Gaze duration did not show a significant three-way interaction between foil type, quantile and relatedness, $F(1,56) = .32$, $p = .58$, indicating that the extent to which the effect of relatedness increased across slower trials did not vary as a function of foil type. In other words, foil probe similarity did not influence the distributional pattern of priming on gaze duration.

However, first-fixation duration did show a significant three-way interaction, $F(1,56) = 6.15$, $p < .05$, and single-fixation duration showed a marginal interaction when the 10th quantile was excluded from the analysis, : $F(1,49) = 22.98$, $p = .09$ (the effect was not significant when all 10 quantiles were included, $F(1,49) = .27$, $p = .61$). Inspection of the Vincentile plots and marginal means indicates for single-fixation and first-fixation duration the effect of priming increased across the distribution more strongly for the dissimilar foils (Experiment 1) than for the similar foils (Experiment 3). Importantly, first-fixation duration and single-fixation duration for the similar foils (Experiment 3) also did not show a main effect of relatedness, indicating that effect of similar foils may generally reduce the effect of semantic priming, rather than specifically affecting the distributional pattern of the effect.

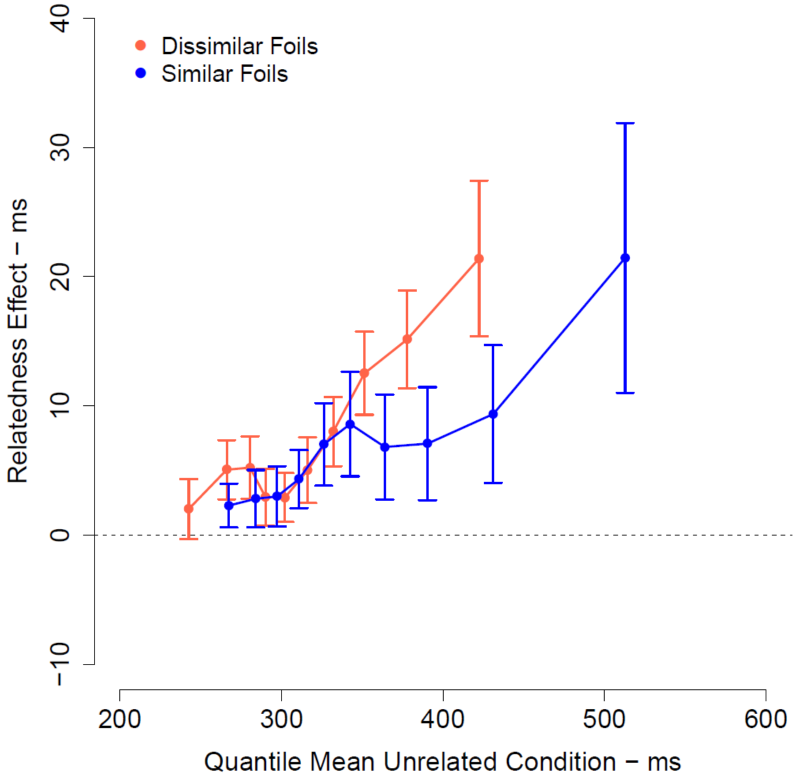
None of the eye movement measures showed a main effect of foil type on estimates of μ, GZD: $F(1,56) = .20$, $p = .66$, FFD: $F(1,56) = .07$, $p = .80$, SFD: $F(1,49) = 1.14$, $p = .29$, indicating that the slower reading times in the similar compared to dissimilar foil experiment are not the result of a general distributional shift. Similarly, there was no effect of foil type on σ for gaze duration, $F(1,56) = 2.27$, $p = .11$ or first-fixation duration, $F(1,56) = 1.41$, $p = .24$, indicating similar degrees of variability across the two foil types. Single-fixation duration showed a marginal effect of foil type on σ, $F(1,49) = 3.29$, $p = .08$, indicating slightly greater variability for the dissimilar compared to the similar foil experiment. Foil type had a significant effect on estimates of τ for gaze duration, $F(1,56) = 10.1$, $p < .01$, and the effect was marginal for single-fixation duration, $F(1, 49) = 3.22$, $p = .08$, but not significant for first-fixation duration, $F(1,56) = .47$, $p = .50$. These results are consistent with quantile analysis of gaze duration, indicating steeper increase (greater skew) across the distribution of reading times in the dissimilar compared to the similar foil experiment.

Relatedness did not affect estimates of μ for gaze duration, F(1,56) = .08, *p* = .77, first-fixation duration, F(1,56) = .19, *p* = .66, or single-fixation duration, F(1,49) = 1.07, *p* = .31. Similarly, none of the measures showed an effect of relatedness on estimates of σ, Fs < 1. Estimates of τ showed a significant effect of relatedness on gaze duration, F(1,56) = 9.23, *p* < .01, so that the distribution of reading times in the unrelated condition showed greater skew than the related condition. The same effect was marginal for single-fixation duration, F(1,49) = 3.04, *p* = .09, but not significant for first-fixation duration, F(1,56) = .44, *p* = .51.

None of the measures indicated that the effect of relatedness on μ varied as a function of foil type, GZD: F(1, 56) = 1.89, *p* = .18, FFD: F(1, 56) = 2.12, *p* = .15, SFD: F(1, 49) = .30, *p* = .58, and the same was found for estimates of σ, Fs < 1, and τ, GZD: F(1, 56) = 1.8, p = .18, SFD: F(1, 49) = .78, *p* = .38, FFD: F(1, 56) = 3.09, *p* = .08, although there was a marginally significant interaction on first-fixation duration, such that the τ-based effect of relatedness (greater skew in the distribution of first-fixation durations on targets in unrelated compared to related trials) was greater for the dissimilar foil probes (Exp 1) than similar foil probes (Exp 3). However, as with the quantile analysis, it should be kept in mind the similar foil experiment generally did not show a significant effect of relatedness on first-fixation duration, so that differences in distributional patterns must be considered within the context of the general magnitude of the effects.

Figure 8

Mean priming effect (gaze duration in the unrelated – related condition) by baseline response speed (average gaze duration in the unrelated condition) in the recognition task with dissimilar foils (Experiment 1) and orthographically similar foils (Experiment 3).



Discussion

Experiment 3 set out to dissociate the effects of task difficulty and response time on the magnitude of the priming effect in the ocular recognition task. While maintaining the same explicit task goals as in Experiment 1, encoding difficulty was increased by using orthographically similar foils. This manipulation encouraged more careful encoding of the stimulus words, as evidenced by increased word encoding times compared to those observed in Experiment 1, and a greater effect of word length. However, even though word reading times in the current experiment were slower compared to Experiment 1, there was no corresponding increase in the magnitude of the priming effect.

Distributional analyses comparing target word reading times across Experiment 1 and 3 showed that the effect of foil type was concentrated in the slow tail of the distribution, as reflected in a significant effect of foil type on τ but not μ or σ. Fast responses did not show a robust effect of foil type, but the magnitude of the foil type effect increased across the slow tail of the distribution. This pattern suggests that participants in the similar foil experiment did not adopt a task strategy that involved a general slowing in response to the more difficult encoding task. Instead, there was greater increase in word encoding times compared to Experiment 1 only in cases where participants experience some degree of difficulty. The finding that reading times in the current experiment also showed a significantly greater effect of word length suggests that encoding difficulty in this case was particularly associated with the number of letters in each stimulus word. Compared to the dissimilar foil probes, the similar foil probes shared a greater number of letters with the stimulus words, increasing the importance of correctly encoding each individual letter. Therefore, there was a greater time-cost associated with each additional letter to be encoded, creating a larger effect of length in the current experiment compared to Experiment 1. As a result, the effect of foil type was concentrated in the slow tail of the distribution, as reading times for long words, which are generally slower, were affected more heavily than reading times for short words, which are generally faster.

Despite the fact that target word reading times in Experiment 3 were slower than in Experiment 1, the magnitude of the priming effect did not vary as a function of foil type. In cases where there appeared to be a difference in priming, it was even in the direction of a smaller priming effect for the current experiment, rather than the other way around. These results suggest that there is no direct relationship between response speed and priming that is independent of task. Instead, prime information has a stronger influence on word reading times for slower, more effortful trials only when the presence of a prime-target relationship can facilitate target processing in the context of the task. In the current experiment, processing difficulty was associated with the encoding of particular orthographic patterns. This task does not directly benefit from the use of related-prime information; hence difficulty with this aspect of the task did not result in greater recruitment of prime information.

The relative reduction in the magnitude of the priming effect found in the current experiment is reminiscent of the prime-task effect, which is the finding that semantic priming is reduced in cases where participants are asked to search the prime for a particular letter (Henik, Kellogg, & Friedrich, 1983; Smith, Theodor, & Franklin, 1983). This effect appears to be specific to orthographic prime tasks, as priming effects are intact when the prime is to be named (Henik et al., 1983); requires a semantic categorization (Smith et al., 1983); or a lexical decision (McNamara & Altarriba, 1988; Tweedy, Lapinski, & Schvaneveldt, 1977), as was also the case in Experiment 2. Similar to our findings, the prime-task effect shows that priming is reduced when participants are asked to direct their attention towards orthographic characteristics of the prime, suggesting that activation of a word's semantic representation is not an unavoidable consequence of reading, but requires at least some degree of directed attention (McNamama, 2005). According to Stolz and Besner's multistage activation model (Borowsky & Besner, 1993; Stolz & Besner, 1996; Stolz & Besner, 1999) the explicit letter identification task requires more attentional resources than the implicit letter identification processes involved in simply reading or categorizing the prime. As a result, attention to the prime is directed toward orthographic level information and away from information at the lexical and semantic levels, so that performance on the letter search is improved at the expense of the efficiency of semantic activation. Although the current experiment did not involve a letter-search task, successful task performance did require attention to be directed toward orthographic information. As a result, attention may have been directed away from semantic information, resulting in the relative reduction in priming.

The current experiment is different from studies using the letter-search prime task, because attention was directed towards orthographic information on both the prime and the target. Therefore, the current data cannot be used to distinguish between the effects of attention towards orthographic information on the prime, the target, or both. In addition, our experiment differs from prime-task studies in the sense that semantic information continues to be at least somewhat relevant to overall task performance. Excluding homographs, there is a consistent one-to-one mapping between orthographic and semantic representations, such that encoding one can facilitate access to the other, and information about the semantic identity of a word may provide top-down facilitation of orthographic encoding and retrieval. This may be reflected in the observation that priming in the similar foil experiment was not completely extinguished, as is often the result of the prime-task effect, but the effect was smaller than would be expected based on the baseline response speed alone.

EXPERIMENT 4 – OCULAR RECOGNITION MEMORY AND POST-TARGET WORD PREVIEW

Consistent with Hoedemaker and Gordon (in press), all three experiments in the current study have found that priming is strongly attenuated in the fast tail of ocular RT distributions. As discussed in the introduction, this finding is consistent with the hypothesis that semantic priming primarily affects the L2 stage of lexical processing in the EZ Reader model. Experiment 4 tests this hypothesis by manipulating the availability of parafoveal preview within the recognition memory task. According to EZ Reader, the duration of the L2 stage does not affect reading times on the currently fixated word, but determines how much information about the upcoming word can be acquired from parafoveal preview. If associative priming during word reading primarily affects the L2 stage of lexical processing, parafoveal preview benefits on the post-target word (appearing in position three of the four stimulus words on each trial) should be more pronounced after related compared to unrelated pairs. In other words, facilitation of target processing by a related prime should manifest as a greater ‘head start’ on processing of the post-target word, so that denial of preview for the post-target word should have more observable consequences after a related compared to an unrelated pair.

Method

Participants. A total of 59 undergraduate students from the University of North Carolina at Chapel Hill participated in the experiment for course credit. All participants were native speakers of English with normal or corrected-to-normal vision. One participant was excluded from all analyses because his or her raw target word reading times were more than three standard deviations above the grand mean. Six subjects showed unusually high skipping rates (at least one word was skipped on over 40% of trials) and were removed from the data, leaving a total of 52 subjects in the analysis.

Materials and design. The stimulus words in Experiment 4 were the same as those in Exeriment 1 and 3. The foil probes were the same as those used in Experiment 1: orthographically dissimilar to the stimulus words.

Procedure. The procedure was identical to Experiments 1 and 3, with the exception of the gaze contingent display and manipulation of parafoveal preview. In order to minimize disruption of the reading process, the first and second word were always available from the beginning of the trial. For half of the related and half of the unrelated trials, the third and fourth word were masked using a gaze contingent display. In contrast to Experiments 1 and 3, the masks were pronounceable nonwords rather than hash marks. By making the masks more word-like, we meant to encourage normal allocation of attention to stimuli in the parafovea. As in the previous experiments, the third and fourth word in the masked condition were revealed when the eyes fixated each word. In order to prevent rereading, each of the four words was covered by a mask of hash marks once the eyes had moved rightward onto the next word. An example stimulus set is presented in Table 24.

Table 24

Example stimuli in the related/unrelated and nonword/identical preview conditions with their respective gaze contingencies in Experiment 4.

	silver gold fusm koss
Related-Nonword preview	#### gold fusm koss
	#### ### horse koss
	#### ### #### tree
	silver gold horse tree
Related-Identical Preview	#### gold horse tree
	#### ### horse tree
	#### ### #### tree
	weird gold fusm koss
Unrelated-Nonword preview	#### gold fusm koss
	#### ### horse koss
	#### ### #### tree
	weird gold horse tree
Unrelated-Identical Preview	#### gold horse tree
	#### ### horse tree
	#### ### #### tree

Analysis of eye movements. Eye movement measures for the prime, target and third-word position are reported as the fourth-word required a key-press response. Fixations shorter than 80 ms and within 1 degree of a longer, immediately subsequent fixation were merged with the longer fixation by an automatic procedure in the EyeLink software. Trials on which either the prime or the target was skipped (9.1% of trials) were removed from the analyses, as were trials on which a boundary was inadvertently triggered due to a blink (.3 % of trials) or because the eye fixated on or very near the boundary instead of on the word (2.2% of trials). Finally, trials on which the participant regressed from the target back to the (then masked) prime rather than progressing to the post-target word were also removed (.1% of trials). As shown in Table 25, the excluded trials were distributed equally across the relatedness and preview conditions. When brief delays in the display change caused a word to be unmasked slightly after the onset of the first fixation on a word, the timestamp of the fixation onset was adjusted to reflect the onset of the word display, excluding any time the participant was fixating the mask rather than the word. The adjustments averaged 5 ms (range 1 – 95 ms). Finally, a reading time cutoff was determined at three standard deviations above the mean for each position in the triplet in each relatedness condition. Gaze durations longer than the relevant cutoff were removed, affecting 1.8% of all words, equally distributed across the related (1.9%) and unrelated (1.8%) trials.

Table 25
*Percentage of trials excluded and number of remaining trials in each condition in Experiment 4***.**

	Priming Condition	
Preview Condition	Related	Unrelated
Identity preview	.15% (34 trials remain)	.14% (34 trials remain)
Nonword preview	.13% (35 trials remain)	.15% (34 trials remain)

Results

Mean accuracy across all participants was 98% (sd = 1.8%, range: 91% - 100%). Gaze durations across the prime, target and third-word position and association condition are presented in Table 26. Mean gaze duration was 350 ms (sd = 52 ms) for unrelated words across all three positions and both preview conditions (i.e., middle words in the related-prime condition were excluded). Mean gaze durations on individual words were correlated with manual response times in the ELP, r = .29, R^2 = .08 p < .001 (N = 477), and negatively correlated with SUBTLEX (Brysbaert & New, 2009) log word frequency, r = -.24, R^2 = .06, p < .001 (N = 480). This correlation is smaller than the effect of frequency observed in Experiment 1 and 3, possibly because the lack of preview availability on the post-target word reduces the effect of frequency on gaze duration. To test this hypothesis, the effect of word frequency on post-target word gaze durations was computed separately for each preview condition and found to be greater when parafoveal preview was available, r = -.17, R^2 = .03, $p < .05$ (N = 160), compared to cases where preview of the post-target word was a nonword mask, r = -.06, R^2 = .003, $p = .44$ (N = 160). Although the two correlations were not significantly different, z = 1.20, $p = .23$ (N = 160), these findings suggest that masking upcoming words in parafoveal preview reduced the effect of word frequency on gaze durations.

Table 26. *Reading times in Experiment 4. All times are in milliseconds. Asterisks identify a significant effect.*

Measure	Condition: Preview	Priming	Word Position: Prime	Target	Post-target
GZD (sd)	Identity Preview	Related pairs	321 (99)	308 (60)	374 (81)
		Unrelated pairs	323 (101)	332 (74)	387 (86)
		Mean	322 (99)	320 (68)	380 (83)
		Priming	2	24	13
	Nonword Preview	Related pairs	--	--	420 (100)
		Unrelated pairs	--	--	429 (99)
		Mean	--	--	424 (99)
		Priming	--	--	9
		Mean Priming	***2***	***24****	***11****
		Priming*Preview	--	--	***2***
FFD (sd)	Identity Preview	Related pairs	236 (37)	261 (44)	290 (61)
		Unrelated pairs	238 (43)	273 (50)	301 (63)
		Mean	237 (40)	267 (47)	295 (62)
		Priming	2	12	11
	Nonword Preview	Related pairs	--	--	324 (75)
		Unrelated pairs	--	--	322 (68)
		Mean	--	--	323 (72)
		Priming	--	--	-2
		Mean Priming	***2***	***12****	***5***
		Priming*Preview	***--***	***--***	***13****
SFD (sd)	Identity Preview	Related pairs	267 (63)	273 (52)	317 (68)
		Unrelated pairs	269 (71)	292 (66)	333 (78)
		Mean	268 (67)	282 (60)	325 (73)
		Priming	2	19	16
	Nonword Preview	Related pairs	--	--	374 (103)
		Unrelated pairs	--	--	373 (94)
		Mean	--	--	374 (98)
		Priming	--	--	-1
		Mean Priming	***2***	***19****	***8***
		Priming*Preview	***--***	***--***	***17****
Proportion Single Fixation Trials (sd)	Identity Preview	Related pairs	.65 (.23)	.76 (.16)	.65 (.19)
		Unrelated pairs	.66 (.22)	.74 (.17)	.63 (.20)
		Mean	.65 (.23)	.75 (.17)	.64 (.20)
		Priming	-.01	.02	.02
	Nonword Preview	Related pairs	--	--	.61 (.22)
		Unrelated pairs	--	--	.58 (.21)
		Mean	--	--	.59 (.21)
		Priming	--	--	.03
		Mean Priming	***-.01***	***.02***	***.03***
		Priming*Preview	***--***	***--***	***-.01***

Target-word reading times. As none of the experiments thus far have found evidence that the effect of relatedness varies across synonyms/antonyms and otherwise-associated pairs, and because the focus of the current experiment is on the effect of preview availability, all analyses for the current experiment will collapse across relationship type.

In a 2 (related vs unrelated) by 2 (preview vs no preview trial) ANOVA, target word gaze durations showed a significant effect of relatedness, $F_1(1,51) = 33.3$, $p < .001$,$F_2(1,159) = 36.1$, $p < .001$, such that targets in the related condition were read more quickly than in the unrelated condition. This effect was also found for single-fixation duration, $F_1(1,51) = 12.84$, $p < .01$,$F_2(1,159) = 17.6$, $p < .001$, and first-fixation duration, $F_1(1,51) = 18.3$, $p < .001$,$F_2(1,159) = 19.1$, $p < .001$. As the target word was never masked (the preview manipulation was applied only to the third and fourth word in each set of four), preview condition was not expected to affect target word reading times. Indeed, we found no evidence for such an effect across any of our measures, all Fs < 1.6. Similarly, the relatedness effect on the target word did not vary as a function of post-target word preview condition for any of the eye movement measures, GZD: $F_1(1,51) = 2.8$, $p = .10$,$F_2(1,159) = 3.9$, $p = .05$, SFD: $F_1(1,51) = .3$, $p = .61$,$F_2(1,159) = 1.6$, $p = .21$, FFD: $F_1(1,51) = 1.0$, $p = .32$,$F_2(1,159) = 2.22$, $p = .14$.

Post-target word reading times. There was a large effect of preview availability across all measures, such that reading times were faster in cases where the post-target word had been available in parafoveal preview compared to cases where parafoveal preview was made unavailable by a nonword mask. GZD: $F_1(1,51) = 65.34$, $p < .001$,$F_2(1,159) = 124.2$, $p < .001$, SFD: $F_1(1,50) = 58.5$, $p <.001$,$F_2(1,159) = 82.3$, $p < .001$, FFD: $F_1(1,51,) = 53.3$, $p < .001$,$F_2(1,159) = 87.3$, $p < .001$. The effect of relatedness was significant on gaze duration, $F_1(1,51) = 8.4$, $p < .01$,$F_2(1,159) = 6.0$, $p < .02$, indicating that post-target words were read more quickly following a related compared to an unrelated target. This effect was marginal by subjects and not significant by items for single-fixation duration, $F_1(1,50) = 4.6$, $p < .05$, $F_2(1,159) = 2.3$, $p = .13$, and not significant for first-fixation duration, $F_1(1,51) = 2.3$, $p = .14$,$F_2(1,159) = 1.7$, $p = .20$.

The main question of this experiment regards whether the priming effect on the post-target word varies as a function of preview availability. This interaction was not significant for gaze duration, $F_1(1,51) = 1.2$, $p = .27$, $F_2(1,159) = 1.2$, $p = .28$, but the effect was significant for first-fixation duration, $F_1(1,51) = 7.3$, $p < .01$, $F_2(1,159) = 10.0$, $p < .01$, and single-fixation duration showed a significant effect by items and a marginal effect by subjects, $F_1(1,50) = 3.72$, $p = .06$,$F_2(1,159) = 4.0$, $p < .05$, such that the foveal-on-parafoveal effect of relatedness on the post-target word was greater when post-target word preview was available compared to when preview was masked.

The EZ reader model was developed based on the assumption that each word receives a single fixation (Reichle et al., 1998; Pollatsek et al., 2006). Therefore, analyses of the post-target reading times were repeated for the subset of trials on which the target word received a single fixation. As can be seen in Table 25, the proportion of single-fixation trials was very similar across the relatedness and preview conditions. For this subset of trials, the main effect of preview continued to be significant across all measures, such that post-target words were read more quickly when preview had been available, GZD: $F_1(1,51) = 35.0$, $p < .001$, $F_2(1,158) = 61.9$, $p < .001$, SFD: $F_1(1,49) = 44.6$, $p <.001$. $F_2(1,159) = 35.00$, $p < .001$, FFD: $F_1(1,51,) = 37.0$, $p < .001$, $F_2(1,159) = 55.3$, $p < .001$. Besides marginal effects for gaze duration and first-fixation duration, the main effect of relatedness was not significant for the subset of trials, GZD: $F_1(1,51) = 5.8$, $p < .05$, $F_2(1,158) = 1.8$, $p = .18$, SFD: $F_1(1,49) = 3.0$, $p = .09$, $F_2(1,159) = 1.0$, $p = .33$, FFD: $F_1(1,51) = 2.3$, $p < .13$, $F_2(1,159) = .9$, $p = .36$..

Consistent with the analysis of the full dataset, the effect of priming on gaze duration on the post-target word did not vary as a function of preview availability, $F_1(1,51) = 1.4$, $p = .25$,$F_2(1,158) = .8$, $p = .38$. There was a significant preview by relatedness interaction on single-fixation duration that was stronger than in the full dataset for the by-subjects analysis, but the effect was now marginal by items, $F_1(1,49) = 7.7$, $p < .01$, $F_2(1,159) = 3.4$, $p = .07$. First-fixation duration showed a slightly weaker interaction effect in the subset compared to the full dataset analysis; the effect was now marginal by subjects but continued to be significant by items, $F_1(1,51) = 3.1$, $p = .09$, $F_2(1,159) = 7.2$, $p < .01$.

Multilevel model analysis. Reading times on the post-target word were also analyzed using multi-level models (MLM). All models were built in the same manner as for 1 and 3. Results of the control model are presented in Table 27 and the random-effect structure is presented in Table 28. All analyses were carried out both for the full dataset and for a subset of trials on which the target word had received a single fixation. Unless otherwise mentioned, the results did not differ across the full and subset analyses, and the pattern of significant main effects did not differ when non-significant interactions were excluded from the model.

The results of the MLMs (Table 29) are largely consistent with results of the ANOVAs. The main effect of preview was significant across all measures. Whereas the ANOVA showed a significant relatedness effect for gaze duration, the MLM only showed this effect once the non-significant relatedness by preview interaction was removed from the model, $t = -2.04$. Although the ANOVA suggested there was an interaction between the effect of relatedness preview availability for single-fixation duration and first-fixation duration, the MLM showed a significant interaction only for first-fixation duration.

Table 27
T-values for control variables included in the MLM for post-target word reading times in Experiment 4. Dashes indicate the control variable was not significant in the control model and excluded from the full model.

	Measure		
Variable	GZD	SFD	FFD
Frequency Target	-2.50	--	--
Frequency Post-Target	--	--	--
GZD Target	8.32	7.22	12.68
Trial Number	-5.71	-5.15	-5.41

Table 28
Random slopes included in the MLM for post-target word reading times Experiment 4. Dashes indicate the random slope was not included in the full model. Asterisks indicate the slope was included in the full model.

	Measure		
Slope	GZD	SFD	FFD
Priming by subjects	*	*	*
Priming by targets	*	-	-

Table 29
Results of the MLM for reading times on the post-target word for Experiment 4. Significant t-values are presented in bold.

	Measure								
	GZD			SFD			FFD		
Main Effects	***b***	**SE**	**t**	***b***	**SE**	**t**	***b***	**SE**	**t**
Related	-6.73	5.04	-1.33	-0.94	4.67	-0.20	6.42	3.79	1.69
Preview	-43.15	2.96	**-14.57**	-44.16	3.09	**-14.29**	-28.53	2.56	**-11.15**
Interaction	***b***	**SE**	**t**	***b***	**SE**	**t**	***b***	**SE**	**t**
Related*Preview	-3.41	5.89	-0.58	-9.48	6.15	-1.54	-12.70	5.10	**-2.49**

Discussion

The goal of Experiment 4 was to test the hypothesis that semantic priming affects primarily the L2 stage of lexical processing. Based on the results of Hoedemaker and Gordon (in press) as well as Experiment 1, 2 and 3, it appears that word encoding and successful lexical decisions can take place before information about the prime-target relationship has had enough time to affect response times. This observation led us to hypothesize that word reading times on fast trials were driven primarily by processes that take place during the L1 stage of lexical processing and any observed priming effects must take place during the L2 stage of lexical processing. According to the EZ reader model, duration of the L2 stage does not affect word fixation times, but affects how much is available to process the upcoming word in parafoveal preview. If semantic priming primarily affects the L2 stage of processing, it should be observable as a foveal-on-parafoveal effect, such that words *following* a related target are read more quickly than words following an unrelated target.

The current experiment did not find compelling evidence that semantic priming primarily affects the L2 stage of processing. We observed a robust preview benefit on all eye movement measures, indicating that participants were able to take advantage of words available in parafoveal preview. However, we did not find a robust interaction between prime-target relatedness and post-target preview availability. First-fixation duration showed a significant interaction between priming and preview availability in the predicted direction but the effect was marginal for single-fixation and not significant for gaze duration. Together, these results do not provide strong evidence that priming occurs during the L2 stages of the EZ-Reader model.

EXPERIMENT 5 – OCULAR RECOGNITION WITH TARGET AND POST-TARGET WORD PREVIEW

Experiment 5 has two goals. The first goal is to re-assess priming as an L2 effect, measured in the degree of foveal-on-parafoveal priming on the post-target word. Experiment 4 did not provide strong evidence that priming occurs during the L2 stages of the EZ-Reader model (Reichle et al., 1998; Pollatsek et al., 2006), as there we did not observe a robust interaction between availability of the post-target word in parafoveal preview and foveal-on-parafoveal priming. However, it is possible that the lack of a robust effect was the result of the display change being too disruptive to normal reading. Display characteristics were not equal between preview conditions: fixation of the post-target word triggered a display change in the nonword preview condition but not in the identity preview condition. In addition, the prime and target words were never masked regardless of condition, making the display change on the post-target word a relatively unusual event. As a result, eye movements may have been more disrupted in the nonword- compared to the identity-preview condition, making a potential effect of preview availability on the magnitude of priming more difficult to detect. Therefore, stimulus presentation in the current experiment was adapted compared to Experiment 4, so that upcoming, not-yet-fixated words were always presented in alternating case font. For example, the post-target word 'treasure' appeared in parafoveal preview as 'TrEaSuRe' in the identity preview condition (identity in this case refers to the orthographic and lexico-semantic identity of the word rather than its typographic form), and as 'ChUrTiSm' in the nonword preview condition. In addition, the prime and target word were also masked by an alternating-case preview mask in all conditions. As a result, fixation of each new word in the set triggers a display change regardless of condition, making the changes in the nonword-preview condition less conspicuous. Previous research has shown that case changes that occur during inter-word saccades do not disrupt eye movements, and alternating case previews do not disrupt the extraction of information in the parafovea (McConkie & Zola, 1979; Rayner, McConkie, & Zola, 1980). Therefore, the use of alternating case preview masks in both the identity- and the nonword-preview conditions is not expected to affect the extent to which the identity previews provide a reading time benefit. If visual differences between the identity and nonword preview conditions in Experiment 4 disrupted normal reading and reduced the reliability of the effect of preview on priming, the current experiment's adaptations in the gaze-contingent display should reduce this disruption and increasing the reliability of a potential foveal-on-parafoveal post-target priming effect.

The second goal is to assess whether preview availability of the target word has an effect on the magnitude of priming effect as measured on target word reading times. If priming primarily affects the L2 stage, availability of target preview should not affect the magnitude of the priming effect on the target. In contrast, if processes contributing to the priming effect on target word reading times are initiated while the target is in parafoveal preview, this may lead to greater target priming when target preview is available compared to when preview is masked. To assess this effect, Experiment 4 manipulates target-preview availability in the same manner as post-target preview availability. On half the trials, the target is masked by a nonword (presented in alternating case) in parafoveal preview, and replaced by the actual target in all lower case upon fixation. If priming depends in part on processes that take place during parafoveal preview, we expect to find a smaller priming effect when parafoveal preview of the target is masked by a nonword compared to cases where the target is available in the parafovea.

Method

Participants. A total of 64 undergraduate students from the University of North Carolina at Chapel Hill participated in the experiment for course credit. All participants were native speakers of English with normal or corrected-to-normal vision. Five subjects showed unusually high skipping rates (at least one word was skipped on over 40% of trials) and were removed from the analysis, leaving a total of 59 subjects.

Materials and design. An example stimulus set is presented in Table 30. The stimulus words in Experiment 5 were the same as those in Experiments 1, 3 and 4, but the information presented in parafoveal preview was different from the previous experiments. Rather than using identity and nonword preview masks, all words were masked with an alternating case preview mask. The first (prime) and fourth (last) word in every set of four were always replaced by alternating case preview masks of the same word (letter-identity preview). Preview of the target and post-target word was manipulated, so that they were either masked by pronounceable nonwords or the identical word, with both the nonword and identity preview masks appearing in alternating case font. Nonword and letter-identity masks were counterbalanced in a 2 (related vs unrelated) x 2 (target word preview: nonword vs letter-identity) x 2 (post-target preview: nonword vs letter-identity) design, so that related and unrelated trials appeared equally often with each of the four possible combinations of target and post-target preview masks. The alternating case masks appeared with the first letter in upper or lower case equally often across relatedness conditions. Upon the first fixation on each word, the mask was replaced by the stimulus word in lower case font. When the eyes moved rightward onto the next word, each word was covered by a mask of hash marks in order to prevent rereading. The foil probes were the same as those used in Experiment 1: orthographically dissimilar to the stimulus words.

Table 30

Example stimuli in a subset of the conditions. All words were presented in alternating case until the eyes fixated the word. Words in the second (targets) and third (post-targets) position were presented with alternating case preview of the identical word (top row) or with a nonword mask that was also displayed in alternating case (bottom row). The table presents only two out of the four possible preview conditions, as preview was counterbalanced in a 2 (target preview: nonword vs identity) x 2 (post-target preview: nonword vs letter-identity) design. Once the eyes left each word region, the word was replaced by a hash mark mask to prevent rereading of previously fixated items.

Letter-Identity Preview	#	kNiFe	fOrK	sAnD	oVaL
	#	knife	fOrK	sAnD	oVaL
	#	####	fork	sAnD	oVaL
	#	####	####	sand	oVaL
	#	####	####	####	oval
Nonword Preview	#	kNiFe	dIvS	fIpE	oVaL
	#	knife	dIvS	fIpE	oVaL
	#	####	fork	fIpE	oVaL
	#	####	####	sand	oVaL
	#	####	####	####	oval

Procedure. The stimuli were presented on a 24” Benq monitor with a resolution of 1920x1080. The use of a 24 point monospace font rendered each character about 15 pixels wide. Participants sat at 30” distance from the display, so that one degree of visual angle spanned approximately three characters. The procedure was identical to Experiment 4.

Analysis of eye movements. Eye movement measures for the prime, target and third-word position are reported, as the fourth-word required a key-press response. Fixations shorter than 80 ms and within 1 degree of a longer, immediately subsequent fixation were merged with the longer fixation by an automatic procedure in the EyeLink software. Trials on which the prime, target or post-target word were skipped (7.5% of trials) were removed from the analyses, as were trials on which a boundary was inadvertently triggered due to a blink (.2 % of trials) or because the eye fixated on or very near the boundary instead of on the word (.8% of trials). Finally, trials on which the participant regressed from the target back to the (then masked) prime rather than progressing to the post-target word were also removed (2.8% of trials). As shown in Table 31, the excluded trials were distributed equally across the relatedness and preview conditions.

When brief delays in the display change caused a word to be unmasked slightly after the onset of the first fixation on a word, the timestamp of the fixation onset was adjusted to reflect the onset of the word display, excluding any time the participant was fixating the mask rather than the word. The adjustments averaged 6 ms (range 1 – 91 ms). Finally, a reading time cutoff was determined at three standard deviations above the mean for each position in the triplet in each relatedness condition. Gaze durations longer than the relevant cutoff were removed, affecting 1.8% of all words, equally distributed across the related (1.7%) and unrelated (1.9%) trials.

Table 31
Percentage of trials excluded from analysis and number of trials that remained in the analysis across relatedness and preview conditions.

		Priming Condition	
Target preview	Post-Target Preview	Related	Unrelated
Letter-Identity	Letter-Identity	10.5 % (18 trials remain)	11.8% (18 trials remain)
	Nonword	9.8 % (18 trials remain)	12.6% (17 trials remain)
Nonword	Letter-Identity	12.9% (17 trials remain)	11.2% (18 trials remain)
	Nonword	11.0% (18 trials remain)	10.7% (18 trials remain)

Results

Mean accuracy across all participants was 98% (sd = 1.9%, range: 91% - 100%). Gaze durations across the prime, target and third-word position and association condition are presented in Table 32. Mean gaze duration was 322 ms (sd = 32 ms) for unrelated words across all three positions and both preview conditions (i.e., middle words in the related-prime condition in all preview conditions were excluded from the analysis of the frequency effect). Mean gaze durations on individual words were positively correlated with manual response times in the ELP, r = .36, R^2 = .13 $p < .001$ (N = 477), and negatively correlated with SUBTLEX (Brysbaert & New, 2009) log word frequency, r = -.31, R^2 = .10, $p < .001$ (N = 480). The effect of word frequency was marginally larger in the current experiment, r = -.31, R^2 = .10 (N = 480), compared to Experiment 4, Fisher's z = 1.95, $p = .05$.

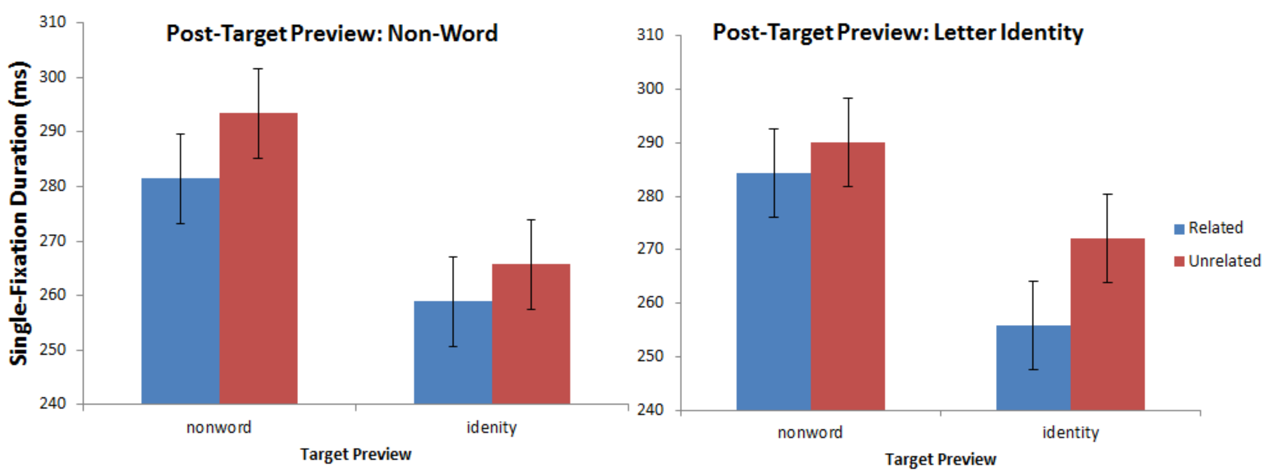
Table 32 *Reading times in Experiment 5. All times are in milliseconds. Asterisks identify significant results.*

	Condition		Word Position		
			Prime	Target	Post-Target
Word GZD (sd)	Letter-Identity Preview	Related pairs	301 (87)	290 (55)	332 (70)
		Unrelated pairs	306 (89)	306 (64)	339 (71)
		Mean	304 (88)	298 (60)	336 (70)
		Priming	5	16	7
	Nonword Preview	Related pairs	--	327 (70)	344 (75)
		Unrelated pairs	--	337 (84)	354 (78)
		Mean	--	331 (76)	349 (76)
		Priming	5	**10**	**10**
		Mean Priming	***--***	***13****	***9***
		Preview*Priming	***--***	***6***	***-3***
Word FFD (sd)	Letter-Identity Preview	Related pairs	214 (43)	257 (44)	281 (51)
		Unrelated pairs	213 (40)	269 (47)	283 (55)
		Mean	213 (42)	263 (46)	282 (53)
		Priming	-1	12	2
	Nonword Preview	Related pairs	--	283 (52)	288 (51)
		Unrelated pairs	--	292 (58)	295 (54)
		Mean	--	287 (55)	291 (53)
		Priming	--	**9**	**7**
		Mean Priming	***-1***	***11****	***5***
		Preview*Priming	***--***	***4***	***-5***
Word SFD (sd)	Letter-Identity Preview	Related pairs	264 (78)	267 (49)	304 (63)
		Unrelated pairs	262 (73)	283 (56)	304 (63)
		Mean	263 (75)	275 (53)	304 (62)
		Priming	-2	16	0
	Nonword Preview	Related pairs	--	302 (64)	310 (62)
		Unrelated pairs	--	313 (76)	322 (76)
		Mean	--	307 (70)	316 (69)
		Priming	--	11	12
		Total Priming	***-2***	***14****	***12***
		Preview*Priming	***--***	***5***	***-12***
Prop Single Fix (sd)	Letter-Identity Preview	Related pairs	.58 (.22)	.81 (.17)	.75 (.20)
		Unrelated pairs	.55 (.22)	.83 (.15)	.73 (.22)
		Mean	.57 (.22)	.82 (.16)	.74 (.21)
		Priming	.03	-.02	.02
	Nonword Preview	Related pairs	--	.77 (.21)	.74 (.21)
		Unrelated pairs	--	.80 (.20)	.73 (.22)
		Mean	--	.78 (.21)	.73 (.21)
		Priming	--	-.03	.01
		Total Priming	***.03***	***-.03***	***.02***
		Preview*Priming	***--***	***.01***	***.01***

Target-word reading times. The effect of preview availability on the magnitude of priming on the target word was assessed using a 2 (related vs unrelated) by 2 (target preview: nonword vs letter-identity) by 2 (post-target preview: nonword vs letter-identity) repeated-measures ANOVA. There was a main effect of target word preview on all eye movement measures, such that targets were read more quickly in the letter-identity compared to the nonword preview condition, GZD: $F_1(1,58) = 70.59$, $p<.001$, $F_2(1,159) = 167.92$, $p < .001$, SFD: $F_1(1,58) = 81.03$, $p < .001$, $F_2(1,159) = 141.84$, $p < .001$, FFD: $F_1(1,58) = 74.72$, $p<.001$, $F_2(1,159) = 134.31$, $p <.001$. There was also a main effect of relatedness, such that targets were read more quickly in the related compared to the unrelated condition, GZD: $F_1(1,58) = 28.09$, $p <.001$, $F_2(1,159) = 19.75$, $p < .001$, SFD: $F_1(1,58) = 19.29$, $p <.001$, $F_2(1,159) = 20.94$, $p <.001$, FFD: $F_1(1,58) = 32.72$, $p <.001$, $F_2(1,159) = 25.70$, $p <.001$.

The crucial interaction of target preview with the effect of relatedness was not significant, GZD: $F_1(1,58) = 2.87$, $p = .10$, $F_2(1,159) = .82$, $p = .37$, SFD: $F_1(1,58) = 1.33$, $p = .25$, $F_2(1,159) = .95$, $p = .33$, FFD: $F_1(1,58) = .46$, $p = .50$, $F_2(1,159) = .13$, $p = .72$. The relatedness by preview interaction on the target word remained non-significant for the subset of trials on which the prime word received a single fixation, $Fs< 1$. As expected, post-target preview availability did not have a significant effect on target word reading times, $Fs< 1$, and the effects of neither target-word preview nor relatedness varied as a function of post-target word preview, $Fs < 1.5$. There was no significant three-way interaction between target-word preview, post-target word preview and relatedness for gaze duration, $F_1(1,58) = 2.74$, $p = .10$, $F_2(1,159) = 1.09$, $p = .30$, but the three-way interaction was significant in the by-subject analysis for single-fixation duration, $F_1(1,58) = 4.86$, $p < .05$, $F_2(1,159) = 2.76$, $p = .10$ and first-fixation duration, $F_1(1,58) = 4.57$, $p < .05$, $F_2(1,159) = 1.42$, $p = .24$. Figure 9 illustrates the nature of the three-way interaction for single-fixation duration. Planned comparisons showed a significant relatedness by target-word preview condition interaction on trials where the post-target word was presented with letter-identity preview, SFD: $F_1(1,58) = 5.81$, $p < .05$, $F_2(1,159) = 3.09$, $p = .09$, FFD: $F_1(1,58) = 3.17$, $p = .08$, $F_2(1,159) = 1.12$, $p = .29$, such that the effect of relatedness was greater in the letter-identity target preview condition, SFD: (mean priming effect: 23 ms), $t_1(58) = -5.76$, $p < .001$, $t_2(159) = -4.16$, $p < .001$, FFD: (mean priming effect: 16 ms) $t_1(58) = -4.33$, $p < .001$, $t_2(159) = -3.55$, $p < .01$, compared to the nonword target preview condition, SFD: (mean priming effect: 4 ms), $t_1(58) = -.67$, $p = .51$, $t_2(159) = -.92$, $p = .36$, FFD: (mean priming effect: 6 ms), $t_1(58) = -1.29$, $p = .20$, $t_2(159) = -1.51$, $p = .13$. On trials where the post-target word was presented with a nonword preview mask, the effect of relatedness on the target word did not differ as a function of target-word preview, SFD: Fs <1, FFD: $F_1(1,58) = 1.09$, $p = .30$, $F_2(1,159) = .35$, $p = .56$. The three-way interaction was not significant for the subset of trials on which the prime received a single fixation, SFD: $F_1(1,52) = 2.81$, $p = .10$, $F_2(1,133) = 2.37$, $p = .13$, FFD: $F_1(1,57) = .32$, $p = .57$, $F_2(1,148) = .71$, $p = .40$).

Figure 9
Three-way interaction between target word preview, post-target word preview and relatedness on single-fixation duration.



Post-target word reading times. The effect of preview availability on the magnitude of priming on the post-target word was assessed using a 2 (related vs unrelated) by 2 (target preview: nonword vs letter-identity) by 2 (post-target preview: nonword vs letter-identity) repeated-measures ANOVA. There was a main effect of target word preview on all eye movement measures, such that post-targets were read more quickly on trials where the post-target word was presented in parafoveal preview with a letter-identity compared to the nonword preview mask, GZD: $F_1(1,58) = 20.25$, $p < .001$, $F_2(1,159) = 16.34$, $p < .001$, SFD: $F_1(1,58) = 14.98$, $p < .001$, $F_2(1,159) = 15.14$, $p < .001$, FFD: $F_1(1,58) = 22.86$, $p < .001$, $F_2(1,159) = 16.59$, $p < .001$. There was also an effect of target word preview, such that post-target words were read more quickly on trials where the target word was presented with a letter-identity preview mask compared to a nonword preview mask, GZD: $F_1(1,58) = 29.93$, $p < .001$, $F_2(1,159) = 28.61$, $p < .001$, SFD: $F_1(1,58) = 13.18$, $p < .01$, $F_2(1,158) = 12.04$, $p < .01$, FFD: $F_1(1,58) = 8.65$, $p < .01$, $F_2(1,159) = 6.30$, $p < .05$. Across preview conditions, there was a small main effect of relatedness, such that post-targets were read slightly faster in the related compared to the unrelated condition, GZD: $F_1(1,58) = 10.81$, $p < .01$, $F_2(1,159) = 6.77$, $p < .05$, SFD: $F_1(1,58) = 5.17$, $p < .05$, $F_2(1,158) = 3.57$, $p = .06$, FFD: $F_1(1,58) = 5.00$, $p < .05$, $F_2(1,159) = 3.82$, $p = .05$.

The crucial interaction between relatedness and preview of the post-target word was not significant, so the effect of relatedness did not vary as a function of post-target preview, GZD: $F_1(1,58) = .65$, $p = .42$, $F_2(1,159) = .47$, $p = .49$, FFD: $F_1(1,58) = 1.08$, $p = .30$, $F_2(1,159) = 1.50$, $p = .22$. The effect was marginal for single-fixation duration in the by-subjects analysis, $F_1(1,58) = 3.10$, $p = .08$, $F_2(1,158) = 2.52$, $p = .11$, but probing the interaction showed that this marginal effect was actually in the opposite direction than predicted, such that priming was greater when the post-target appeared with nonword preview (mean priming effect: 12 ms), $t_1(58) = -2.55$, $p < .05$, $t_2(159) = -2.76$, $p < .01$, compared letter-identity preview (mean priming effect: 0 ms), $t_1(58) = -.11$, $p = .91$, $t_2(159) = -.82$, $p = .41$. Moreover, the effect disappeared when we assessed the subset of trials of the subset of trials on which the target received a single fixation, Fs <1.

The effect of relatedness did not vary as a function of target word preview condition and there was no interaction between target word preview and post-target word preview. There was no three-way interaction between relatedness, target-word preview and post-target preview, all Fs <1.

Multilevel model analysis. The effects relatedness and preview availability were also analyzed using multi-level models (MLM). Separate models were built for each eye-movement measure on the target and post-target word, using the same procedure as for the previous experiments. To match the ANOVAs, all two-way interactions and the three-way interaction between relatedness, target-word preview and post-target preview were included in the initial model. Subsequently, we assessed each model including only the main effects and the main interaction of interest: the effect of relatedness as a function of the preview condition on the fixated word. Unless otherwise mentioned, the results were the same across models that included non-significant interactions and those that did not. Results of the control model are presented in Table 33 (target) and 34 (post-target), and the random-effects structure is presented in Table 35 (target) and Table 36 (post-target).

The results of the multi-level analysis on the target word are presented in Table 37. The results are largely consistent with the ANOVA. Target word reading times showed a main effect of target preview availability and relatedness on all eye movement measures. Consistent with the ANOVA, single-fixation duration showed a significant three-way interaction between relatedness, target-word preview and post-target preview (see Figure 9), but unlike the ANOVA this effect was not significant for first-fixation duration. No other main effects or interactions approached significance. None of the effects were different when only trials on which the prime received a single fixation were included in the model.

Results of the full model predicting post-target reading times are presented in Table 38. The results for the main effect appear to be somewhat more conservative than suggested by the ANOVA. Consistent with the ANOVA, there was a main effect of post-target preview on all measures, but unlike the ANOVA the effects of relatedness and target preview were significant only for gaze duration. Whereas the ANOVA also showed a significant effect of target word preview, this effect was significant for gaze duration but not single- and first-fixation in the MLM. There were no significant interactions. When only crucial relatedness by post-target preview interaction was included in the model, the main effect of relatedness remained significant for gaze duration, $t = -2.29$, and also reached significance for single-fixation duration, $t = -2.20$, but not for first-fixation duration, $t = -.45$. The relatedness by post-target preview interaction remained non-significant for all measures. None of the effects were different when only trials on which the target received a single fixation were included in the model.

Table 33
T-values for control variables included in the MLM for the effect of priming on target word reading times in Experiment 5. Dashes indicate the control variable was not significant in the control model and excluded from the full model.

	Measure		
Variable	GZD	SFD	FFD
Prime freq	-4.63	-3.30	-
Target Freq	-3.65	-3.49	-2.88
GZD prime	9.80	9.44	12.57
Trial number	-9.42	-7.01	-6.27

Table 34
T-values for control variables included in the MLM for the effect of priming on post-target word reading times in Experiment 5. Dashes indicate the control variable was not significant in the control model and excluded from the full model.

	Measure		
Variables	GZD	SFD	FFD
Target Freq	-	-	-
Post-target freq	-4.51	-4.22	-2.86
GZD target	8.99	11.99	16.96
Trial number	-5.63	-4.80	-3.16

Table 35
Random slopes included in the MLM for the effect of priming on target word reading times Experiment 5. Dashes indicate the random slope was not included in the full model. Asterisks indicate the slope was included in the full model.

	Measure		
Slope	GZD	SFD	FFD
Priming by subjects	-	-	-
Priming by items	*	*	*

Table 36
Random slopes included in the MLM for the effect of priming on post-target word reading times Experiment 5. Dashes indicate the random slope was not included in the full model. Asterisks indicate the slope was included in the full model.

	Measure		
Slope	GZD	SFD	FFD
Priming by subjects	*	*	*
Priming by items	*	*	*

Table 37

Results of the MLM for the effect of priming on reading times on the target word for Experiment 5. Rel. = Related. T = Target. PT = Post-Target. Prev. = Preview. Significant t-values are presented in bold.

	Measure								
	GZD			SFD			FFD		
Main Effects	***b***	**SE**	**t**	***b***	**SE**	**t**	***b***	**SE**	**t**
Related	-12.87	4.16	**-3.09**	-11.58	3.92	**-2.96**	-11.72	3.67	**-3.19**
Target Prev.	-32.92	2.85	**-11.56**	-30.31	2.75	**-11.04**	-24.55	2.59	**-9.47**
Post-Target Prev.	-0.73	2.86	-0.25	-0.09	2.78	-0.03	-1.35	2.60	-0.52
Interactions	***b***	**SE**	**t**	***b***	**SE**	**t**	***b***	**SE**	**t**
Rel.*Target Prev.	1.43	5.69	0.25	3.23	5.48	0.59	5.15	5.18	0.99
Rel.*PT Prev.	7.29	5.71	1.28	10.24	5.55	1.85	6.54	5.20	1.26
T.Prev. * PT Prev.	-1.61	4.04	-0.40	0.86	.88	0.22	2.13	3.68	0.58
Rel.*T.Prev.* PT. Prev.	-14.91	8.07	-1.85	-22.85	7.76	**-2.95**	-14.35	7.35	-1.95

Table 38

Results of the MLM for the effect of priming on reading times on the post-target word for Experiment 5. Rel. = Related. T = Target. PT = Post-Target. Prev. = Preview. Significant t-values are presented in bold.

	Measure								
	GZD			SFD			FFD		
Main Effects	***b***	**SE**	**t**	***b***	**SE**	**t**	***b***	**SE**	**t**
Related	-5.76	4.61	-1.25	-5.95	4.40	-1.35	-3.59	3.95	-0.91
Target Prev.	-11.67	3.09	**-3.78**	-3.48	2.96	-1.17	0.71	2.76	0.26
Post-Target Prev.	-13.74	3.08	**-4.47**	-10.67	2.97	**-3.59**	-9.25	2.75	**-3.36**
Interactions	***b***	**SE**	**t**	***b***	**SE**	**t**	***b***	**SE**	**t**
Rel.*Target Prev.	-4.29	6.12	-0.70	-2.51	5.87	-0.43	-0.68	5.48	-0.12
Rel.*PT Prev.	-0.11	6.15	-0.02	9.44	5.94	1.59	4.67	5.50	0.85
T.Prev.*PT.Prev.	2.33	4.34	0.54	-2.28	4.15	-0.55	-1.11	3.88	-0.29
Rel.*T.Prev* PT.Prev.	6.51	8.68	0.75	-2.29	8.30	-0.28	0.83	7.76	0.11

Multi-level model analysis for the effects of word frequency and preview. We did not find strong evidence to support the notion that the magnitude of the priming effect depends on parafoveal preview availability, whether measured on the target or the post-target word. In order to verify whether the current experiment was able to detect any differences in foveal-on-parafoveal effects as a function of preview availability, we tested whether the effect of word frequency varied as a function of preview availability.

We assessed whether the effect of word frequency on the current (target and post-target) and the previous word (prime and target) varied as a function of preview availability of the target word, the post-target word or both. As word frequency was not manipulated or counterbalanced across relatedness and preview conditions in the current experiment, the effects of prime frequency, target frequency, target preview availability and post-target preview availability were assessed in a multi-level model. Frequency was always entered as a continuous predictor and preview availability as a discrete predictor. The control model always included gaze duration on the previous word, relatedness condition and the trial number. Results of the control model are presented in Table 39 (target) and 40 (post-target), and the random-effects structure is presented in Table 41 (target) and Table 42 (post-target).

Results of the model of target word reading times are presented in Table 43. Initial tests of the models for target word reading times showed that there were no significant interactions for any of the main effects with post-target preview, so these interactions were excluded from all models. Consistent with the analysis of the relatedness effect, we found a main effect of target preview on all measures, such that targets were read more quickly when letter-identity preview was available compared to when preview was masked. There was a main effect of target frequency in the expected direction, such that high frequency targets were read more quickly than low-frequency targets. The effect of target frequency did not differ as a function of target preview availability, both in the full model and when this was the only included interaction. Prime frequency had a main effect such that target word gaze durations were shorter following a high frequency prime. This main effect was not significant for single-fixation duration or first-fixation duration, but for these measures the effect of prime frequency varied significantly as a function of target preview availability, such that the effect of prime frequency had a greater foveal-on-parafoveal effect on target word reading times when the target was presented with letter-identity compared to nonword-mask preview. When prime frequency by target preview was the only interaction included in the model, the effect was also significant for gaze duration, $t = -2.19$, and was strengthened for single-fixation duration, $t = -3.07$, and first-fixation duration, $t = -3.19$. To illustrate this effect, the raw correlation between prime frequency and target word gaze duration was -.33, $R^2 = .11$ for targets with identical preview and -.17, $R^2 = .03$ ($N = 320$) when the target was presented with a nonword preview mask.

The effects of word frequency and preview availability on the post-target word (Table 44) were assessed in the same manner as for the target. None of the measures showed a significant three-way interaction between post-target frequency, post-target preview and target word preview so this interaction was not included in the models. However, gaze duration showed a significant three-way interaction between target frequency, post-target preview and target preview, and therefore the interaction was maintained in all models.

Consistent with all previous analyses, there was a main effect of post-target preview availability on all measures except number of first-pass fixations, so that post-target words were read more quickly when preview had been available, and a main effect of target word preview availability on gaze duration, such that post-target words were read more quickly following a letter-identity preview target compared to a nonword-preview target. In addition, there was a main effect of post-target frequency in the expected direction on all measures, so that high frequency post-target words were read more quickly than low-frequency post-target words. Target word frequency did not have a main effect on post-target reading times, but gaze duration and single-fixation duration showed a significant interaction between target frequency and post-target preview availability, such that the effect of target word frequency on post-target word reading times was greater for post-target words in the letter-identity preview (GZD: b = -6.04, t = -1.61, SFD: b = -6.24, t = -1.86) compared to the nonword preview condition (GZD: b = 2.51, t = .67, SFD: b = 2.42, t = .73). Gaze duration also showed a significant three-way interaction between target frequency, post-target preview and target preview conditions, but the individual effects did not indicate a clear pattern of results and given the number of comparisons performed this three-way interaction was deemed not to merit interpretation. Interestingly, when the three-way interaction between target preview, target frequency and post-target preview was removed from the model, the target frequency by post-target preview interaction was substantially weakened compared to the full model (SFD: t = -1.18, FFD: t = -.81). In other words, inclusion of the interactions with target preview strengthened the foveal-on-parafoveal effect of target frequency on the post-target word, suggesting that the manipulation of target preview may have somewhat disrupted the expected target frequency spillover effect. All other results remained unaltered regardless of which set of interactions was included in the model.

Table 39

T-values for control variables included in the MLM for the effects of frequency and preview availability on target word reading times in Experiment 5. Dashes indicate the control variable was not significant in the control model and excluded from the full model.

	Measure		
Variable	GZD	SFD	FFD
GZD prime	10.58	10.19	12.83
Related	-6.15	-5.59	-5.18
Trial Number	-9.19	-7.12	-6.06

Table 40

T-values for control variables included in the MLM for the effects of frequency and preview availability on post-target word reading times in Experiment 5. Dashes indicate the control variable was not significant in the control model and excluded from the full model.

	Measure		
Variable	GZD	SFD	FFD
GZD Target	8.85	12.02	16.93
Related	-2.86	--	--
Trial Number	-5.65	-4.94	-3.24

Table 41

Random slopes included in the MLM for the effects of frequency and preview availability on target word reading times Experiment 5. Dashes indicate the random slope was not included in the full model. Asterisks indicate the slope was included in the full model.

	Measure		
Slope	GZD	SFD	FFD
Target preview by subjects	*	*	*
Target preview slope by items	-	-	-

Table 42

Random slopes included in the MLM for the effects of frequency and preview availability on post-target word reading times Experiment 5. Dashes indicate the random slope was not included in the full model. Asterisks indicate the slope was included in the full model.

	Measure		
Slope	GZD	SFD	FFD
Post-Target Preview slope by subjects	*	*	*
Post-Target Preview slope by items	-	-	*

Table 43

Results of the MLM for the effects of frequency and preview availability on target word reading times for Experiment 5. Significant t-values are presented in bold.

	Measure								
	GZD			SFD			FFD		
Main Effects	***b***	**SE**	**t**	***b***	**SE**	**t**	***b***	**SE**	**t**
Target Preview	-34.05	4.14	**-8.23**	-30.95	3.65	**-8.49**	-23.54	2.78	**-8.46**
Prime Freq.	-6.95	2.21	**-3.15**	-1.89	2.10	-0.90	0.90	1.96	0.46
Target Freq.	-6.56	2.62	**-2.51**	-5.54	2.25	**-2.46**	-4.59	2.11	**-2.17**
Post-Target Preview	-1.55	2.00	-0.77	.01	1.92	0.00	-0.21	1.83	-0.11
Interactions	***b***	**SE**	**t**	***b***	**SE**	**t**	***b***	**SE**	**t**
Prime Freq. * Target Preview	-5.34	2.85	-1.88	-7.96	2.76	**-2.89**	-7.99	2.60	**-3.07**
Target Freq. by Target Preview	-4.01	2.82	-1.42	-1.56	2.69	-0.58	-0.83	2.57	-0.32

Table 44

Results of the MLM for the effects of frequency and preview availability on post-target word reading times for Experiment 5. Significant t-values are presented in bold.

	Measure								
	GZD			SFD			FFD		
Main Effects	***b***	**SE**	**t**	***b***	**SE**	**t**	***b***	**SE**	**t**
Post-Target Preview	-13.85	3.60	**-3.85**	-11.23	3.62	**-3.10**	-9.20	2.86	**-3.22**
Post-Target Freq.	-11.87	3.35	**-3.54**	-10.63	2.84	**-3.74**	-6.82	2.64	**-2.59**
Target Freq.	2.46	3.72	0.66	2.48	3.30	0.75	3.09	3.06	1.01
Target Preview	-11.93	3.09	**-3.86**	-3.88	2.96	-1.31	0.74	2.76	0.27
Interactions	***b***	**SE**	**t**	***b***	**SE**	**t**	***b***	**SE**	**t**
Target Freq* PT.Preview	-8.56	4.22	**-2.03**	-8.71	4.08	**-2.13**	-6.41	3.84	-1.67
PT.Freq.* PT.Preview	-2.34	3.25	-0.72	1.24	3.13	0.40	2.23	3.00	0.74
Target Freq*PT.Prev. *Target Prev.	13.24	5.97	**2.22**	10.42	5.69	1.83	8.36	5.34	1.57

Discussion

Experiment 5 set out to test the hypothesis that semantic priming primarily affects EZ Reader's L2 stage of lexical process, and thus should be observed primarily as a foveal-on-parafoveal or post-target word spillover effect. In relation to Experiment 4, we aimed to reduce the amount of disruption caused by the gaze-contingent display changes by using an alternating case preview on every word, so every saccade to the next word triggered a display change regardless of preview (nonword vs identity) condition. Although we do not have direct evidence about how the alternating case previews affected word reading in this task, the data do suggest that reading in the current experiment was less disrupted than in Experiment 4. Overall average reading times were faster in the current experiment (322 ms) compared to Experiment 4 (350 ms), and the effect of word frequency was slightly larger.

Nonetheless, we did not find evidence that semantic priming primarily affects spillover on the post-target word. Post-target reading times showed a robust effect of preview availability, and some of the eye movement measures also showed an effect of prime-target relatedness. However, there was no evidence that the priming effect on the post-target word was greater in cases where post-target preview was available compared to cases where preview of the post-target word was masked. Therefore, the current experiment does not provide evidence that semantic priming selectively affects the L2 stage of lexical processing. A possible explanation for this lack of results is that the concurrent, counterbalanced manipulation of both target and post-target word preview introduced a large amount of variance, masking subtle interactions of priming with preview on the target, the post-target or both. Target word preview had a significant main effect on post-target word reading times, such that reading on the post-target was slower after a masked compared to a non-masked target. These results suggest that manipulation of preview of the target word may have introduced enough variability to mask the hypothesized priming-by-preview interaction.

We also did not find evidence that preview availability of the target word affected the magnitude of the priming effect as measured on target word reading times. This finding is consistent with the well-established finding that preview masks that are semantically related to the target (e.g., preview word 'warm' is replaced by 'cold' upon fixation) do not provide a preview benefit during normal sentence reading (Altarriba, Kambe, Pollatsek, & Rayner, 2001; Drieghe, Rayner, & Pollatsek, 2005; Rayner et al., 1980; Rayner, Balota, & Pollatsek, 1986; Rayner, Schotter, & Drieghe, 2014; for a review see Schotter, Angele, & Rayner, 2012). Taken together, these results suggest that semantic information does not affect processing of words in parafoveal preview. However, the priming effect in Experiment 4, when the prime was never masked, was bigger (24 ms) than the average priming effect in the current experiment across preview conditions (13 ms), and bigger than the priming effect in Experiment 1, when the prime was always masked by hash marks (10 ms). There are two possible explanations for this. On the one hand, it is possible that the use of mask (alternating case letter-identity and nonword preview masks in the current experiment, hash mark masks in Experiment 1) caused some disruption to the normal reading process, reducing the overall effect of priming on the target word. If so, there would be no reason to believe that processing of words in the parafovea is affected by semantic information. On the other hand, it is possible that the use of alternating case letter-identity and nonword preview masks in the current experiment discouraged readers from attempting to gain information from words in parafoveal preview. This would explain why the effect of preview availability is much bigger when compared between Experiments 1 (target always masked) and 4 (target never masked) (10 ms and 24 ms priming effects respectively), than when compared within-subjects for the current experiment (priming effects of 16 ms in the letter-identity preview and 10 ms in the nonword preview condition). It must be kept in mind that the data for Experiments 1 and 4 were gathered at different points in the semester, and the cross-experiment comparison should be interpreted with caution. Nonetheless, these results suggest that the effect of preview availability on the magnitude of priming is best addressed between participants rather than within participants. Therefore, this issue should ideally be addressed within a single experiment but between participants. Finally, manipulation of preview of the post-target word may also have unduly affected the priming by preview interaction on the target word. Target word reading times showed a weak three-way interaction between priming, target-word preview and post-target preview, such that the crucial priming by target preview interaction was significant only on trials where the post-target was presented 'normally,' with letter-identity preview. Similar to the results for the post-target word, the concurrent counterbalanced manipulation of preview of both the target and the post-target introduced enough variability to mask any priming-by-preview interaction.

It has been well established that during normal sentence reading, word reading times on words following a high-frequency word are faster than reading times on words following a low-frequency words (e.g., Rayner & Duffy, 1986; Rayner, et al., 1989). The EZ Reader model can account for this foveal-on-parafoveal or 'spillover' effect by virtue of its two-stage model of processing. For easy to recognize, high frequency words, recognition completed relatively quickly, leaving more time for parafoveal processing of the upcoming word which reduces the processing time once it is eventually fixated. More difficult, low-frequency words leave less time between the completion of word recognition and the execution of the next saccade, so that this difficulty 'spills over' to the next word in the form of reduced parafoveal preview benefit

(Reichle et al., 1998; Pollatsek et al., 2006). In addition, there has been some evidence that the effect of frequency of the currently fixated word is stronger when that word has been available in the parafovea prior to fixation as compared to when preview was masked (Reingold, Reichle, Glaholt, & Sheridan, 2012)).

Target word reading times in the current experiment showed a reliable interaction between target preview and the frequency of the prime word in the expected direction, such that prime frequency spillover was greater for targets with identity preview compared to nonword preview. This result is consistent with the predictions of EZ Reader. The same effect was also observed on post-target word reading times, although somewhat less robust, in the form of a target word frequency by post-target word preview interaction. However, there was some evidence that this interaction was also affected by target-word preview availability. Similar to the analysis of the priming by preview interaction, these results suggest that concurrent manipulation of the target and post-target preview may have unduly masked some of the interactions of interest. In contrast, we did not find an interaction between preview and frequency of the current word, either on the target or post-target, as opposed the frequency of the previous word. This result is inconsistent with Reingold et al's (2012) observation that frequency effects are larger for words that had been available in parafoveal preview. However, as the frequency by preview interaction was analyzed in a post-hoc fashion, we cannot draw strong conclusions on the basis of this null effect.

In summary, observation of the frequency spillover effects suggests that foveal-on-parafoveal effects *can* be detected in the current design. However, we did not find clear evidence for a foveal-on-parafoveal effect of semantic priming, either on the target or the post-target word, perhaps because concurrent manipulation of both target and post-target preview disrupted the relatedness by preview interaction on the target, the post-target or both words. As a result, the experiment does not provide a clear picture of the way in which semantic priming affects word recognition within the EZ Reader model's two-stage framework.

GENERAL DISCUSSION

Semantic priming is very robust in tasks involving the recognition of words in isolation, such as lexical decision tasks, but is quite limited during text reading. We evaluated the role of meaning-based relationships on the effect of priming, as well the mechanisms of priming during word reading in relation to the task-related processing goals of the reader. The project had three main goals. First, it investigated how meaning-based prime-target relationships affect priming (Experiment 1 and 3). Post-hoc analyses of pilot data suggested that priming during the ocular recognition task was stronger for antonyms (and possibly synonyms) than for otherwise-associated prime-target pairs. No such effect was found when the same stimuli were used in an ocular LDT, suggesting that the role of prime-target relatedness might vary as a function of the task goals and/or response speed of the reader. Experiments 1 and 3 addressed these questions experimentally by using groups of synonym, antonym and otherwise-associated pairs that were balanced for forward (FAS) and backward association strength (BAS) as well as the strength of the priming effect in an LDT based on the Semantic Priming Project database (Hutchison et al., 2013). The results did not confirm the effects suggested by the pilot data, as there was no difference in priming between synonyms, antonyms and otherwise-associated pairs. Priming in the lexical decision task showed a small effect of FAS but not BAS or SPP priming strength, and none of these factors affected priming in the ocular recognition task.

Our second goal was to assess the mechanism by which semantic relatedness affects word recognition during reading in relation to the task-based goals of the reader. We compared the magnitude of the semantic priming effect across ocular LDT (Experiment 2) and recognition memory tasks (Experiments 1 and 3). Word reading times on the target word showed reliable priming on word reading times across both tasks. The effect was consistently concentrated in the slow tail of the distribution, such that fast responses showed little to no effect of relatedness, and the effect gradually increased in magnitude across the slow tail of the distribution. Analysis of the condition means showed that the effect of relatedness was greater in the LDT than the recognition task. However, comparison of the priming effect as a function of baseline response times across Experiment 1 and 2 showed that for the portion of the distribution on which response times in the LDT and recognition task overlapped, the magnitude of the priming effect was similar across the two tasks. To further dissociate the effects of task and response speed on semantic priming, Experiment 3 used foil probes that were orthographically similar to the stimulus words, so that encoding difficulty was increased while the explicit goals of the task remained the same. Although word reading times were significantly slower in Experiment 3 compared to Experiment 1, there was no corresponding increase in the magnitude of the priming effect.

The third and final goal of the current project was to assess how semantic relatedness affects the planning and execution of forward saccades during word reading. Specifically, we tested the hypothesis that semantic priming primarily affects the L2 stage of the EZ Reader model of eye movements during reading, and thus should be observed in the form of a foveal-on-parafoveal or ‘spillover’ effect on the post-target word. We manipulated parafoveal preview availability of the post-target word (Experiment 4) and of both the target and the post-target word in a counterbalanced within-subjects design (Experiment 5). We did not find reliable evidence that parafoveal preview benefit on the post-target word was greater following a related compared to an unrelated target. Therefore, these data do not support the hypothesis that semantic priming primarily affects the L2 stage of lexical processing. Similarly, the magnitude of the priming effect on target word reading times did not vary as a function of target word availability in parafoveal preview, suggesting that semantic priming is not affected by processes that take place during parafoveal processing of upcoming related or unrelated targets. However, post-hoc analyses showed a significant foveal-on-parafoveal effect of word frequency, such that both the target and post-target word reading times were faster when the preceding word was high frequency, and the amount of spillover was greater in cases where the word had been available in parafoveal preview.

Meaning-Based Priming is Driven by Associative Relationships

Characterization of the ways in which specific semantic prime-target relationships affect priming is of interest because models of semantic memory generate different predictions regarding which types of semantic and associative connections should show priming. We assessed a new hypothesis on the role of meaning-based relationships during priming based on the results of a pilot study, which suggested that, on tasks that did not require a metalinguistic judgment, priming was greater for synonym/antonym pairs than otherwise-associated pairs. Because the results of the current project did not confirm the post-hoc analyses of the pilot data, it is difficult to align our findings with prior studies on this topic. For example, the current results do not provide evidence to support models of semantic memory in which concepts are connected by virtue of overlapping features, such as distributed network models (e.g., Moss et al., 1994; Plaut, 1995; McRae et al., 1997) and holistic associative network models in which concept nodes are connected by virtue of shared features (e.g., Collins & Loftus, 1975). However, the stimuli in the current study were not selected specifically to assess the effect of degree of feature overlap on priming. Instead, relationship type was used as a proxy for feature overlap as synonyms and antonyms share a large number of features while otherwise-associated pairs may share a large number of features (e.g., category coordinates: *broccoli – cauliflower*), or virtually none (e.g., functional relationships: *airport – plane).* As a result, the otherwise-associated stimuli may have included too many pairs that also shared a relatively high number of features, diminishing the validity of any feature-based differences between the stimulus groups. Specific feature norms are not available for the prime-target pairs used in this study, but the otherwise-associated pairs included enough category coordinates (30 out of 80 pairs) that this could plausibly account for our results. Similarly, Hutchison's (2003) meta-analysis concluded that semantic priming is stronger for some types of semantic relationships, specifically synonyms, antonyms and functionally related pairs, than other kinds of relationships, notably category coordinates and perceptually similar pairs. However, the otherwise-associated pairs in our study also included functionally related pairs, thus mixing the types of relationships which according to Hutchison should and should not cause priming. Finally, our results are consistent with studies that have found no difference in priming for pairs based on relationship type during LDT (Hodgson, 1991; Perea & Gotor, 1997; Perea & Rosa, 2002), even though these studies used semantically related prime-target pairs that had no or very low associative relationships, while our stimuli included a range of forward and backward association strengths. Future studies on the role of semantic relationship types and priming will need to consider more specific relationship types rather treating the 'otherwise-associated' as single category. In addition, the role of feature overlap should be addressed in a more targeted manner by specifically manipulating degree of feature overlap independently of relationship type.

Studies that have addressed the role of relationship type have typically done so using prime-target pairs that are not considered associated based free-association norms in an attempt to separate the effects of associative and semantic or feature-based connections (e.g., Hutchison, 2003). As it has proven almost impossible to create pairs that are connected purely by virtue of either semantics or association but not the other, the current project chose to include a range of FAS and BAS values within each relationship type and assess both the effects of relationship type and associative strength across the same stimulus pairs. The finding that the magnitude of the priming was not strongly related to FAS is consistent with prior reports showing no relationship between association strength and priming, (Hodgson, 1991; Perea & Rosa, 2002; Fischler, 1977; Hines, Czerwinski, Sawyer, & Dwyer, 1986), even though the current stimuli included a much wider range of association strength values than typically used in these studies. These results suggest that semantic priming emerges as a discrete event, such that the magnitude of the effect does not depend on the degree of associative strength. However, it should be kept in mind that the magnitude of the priming effect is based on a difference score, such that the prime-target pairing in the unrelated condition could have strong influence on the observed magnitude of priming. The consequences of using a difference score become especially clear in relation to the SPP (Hutchison et al., 2013). We did not find a relationship between the magnitude of the priming effect in our study and in the SPP database for the same prime-target pairs. Crucially, the targets in our study were paired with different unrelated primes than in the SPP, a concession that was necessary to allow for proper counterbalancing, so that different response times in the unrelated condition may have affected the observed magnitude of priming. In contrast, word reading times across all word positions showed strong relationships to LD times in the English Lexicon Project (Balota et al., 2007), which provides average LD response times to individual words rather than difference scores. These results show that it is very difficult to make predictions about the magnitude of the priming effect across studies unless consistent prime-target pairings are maintained in both the related and the unrelated condition.

Taken together, our results are consistent with the general literature on the nature of meaning-based relationships and priming. The concept of association, or a general sense of which words tend to 'go together' continues to be the strongest predictor of priming, and attempts to further specify of the types of semantic relationships that drive priming do not yield clear results or considerable additional explanatory power. As such, if meaning-based priming is considered to reflect true relations of meaning within semantic knowledge, the strongest evidence suggests that the semantic network is organized primarily according to principles of experience, such that concepts that are often experienced together tend to be more closely connected.

Meaning-based Priming is a Marker of Processing Difficulty

Across experiments, we did not find strong evidence that priming during word recognition operates as a prospective mechanism. Instead, our results indicate that priming occurred through a retrospective mechanism that is primarily associated with processing effort or difficulty. The remainder of our results helps to further characterize this effort-related, retrospective priming mechanism. We found no evidence that the retrospective priming mechanism operated specifically in service of the word-nonword decision in the LDT. Average response times were much slower in the LDT than the recognition task, so that the condition means showed greater priming in the LDT and the recognition task. However, comparison of priming across Experiments 1 and 2 suggests that on trials where baseline response times were equal, the magnitude of the priming effect did not vary as a function of task, suggesting that the meta-linguistic requirements of the LDT do not enhance priming independently of response speed.

Even though we have characterized priming during reading as a retrospective mechanism, we did not find evidence that the magnitude of the semantic priming effect was related to the degree of backward (target-to-prime) associative strength. This finding weakens the notion that τ-based priming is the result of the active, goal-driven recruitment of prime information specifically for the purpose of making a binary task-based decision on the target. Instead, these results are consistent with Thomas et al. (2012), who find τ-based priming across both LDT and naming tasks, the latter of which does not require a word-nonword decision. Thomas and colleagues provide two possible explanations for these findings. According to the decision-level account, detection of a semantic relationship between the target and the prime increases one's confidence in the response, reducing the criterion to begin responding. According to the alternative lexical-level account, detection of a prime-target relationship reduces the amount of visual information required to determine the correct response, thereby speeding up word recognition and reducing response times. In the current study, word reading times in the ocular recognition task do not reflect an explicit, task-related decision, reducing the plausibility of Thomas et al's decision-level account. This leaves the lexical access account, suggesting that retrospective access to information about the prime-target relationship can facilitate the lexico-semantic processing stage of word recognition during reading independently from the specific task-related processing goals of the reader. As such, the compound cue model (Ratcliff & McKoon, 1988, De Wit & Kinshita, 2015) might be adapted to account for our data by assuming that the prime-target information can be used as one of the cues to the identity of the word, rather than driving the word-nonword decision through post-lexical semantic matching. Similarly, Balota and colleagues' 'race' model may be able to account for the current data if we drop the assumption that the race between bottom-up information about the target word and top-down information about the prime-target relationship occurs only during the LDT. Instead, the race mechanism may affect word recognition times across tasks, regardless of the specific processing goals of the reader. Finally, within the study of eye movements during sentence reading, τ has been characterized primarily as a measure of processing disruption (Staub & Benatar, 2013). Therefore, τ-based priming may be an indicator that the priming effect primarily reflects inhibition or disruption in the unrelated condition rather than a facilitatory effect in the related condition. Again, the disruption may occur at the level of lexico-semantic access rather than the task-specific decision stage, such that its effects are observed across tasks regardless of task-specific processing goals and response criteria.

Even though the magnitude of the priming effect was more strongly related to baseline response speed than to the goals of the task, Experiment 3 showed that priming is not fully independent of task-specific processing goals. As discussed, this observation is consistent with Stolz and Besner's multistage activation model (Borowsky & Besner, 1993; Stolz & Besner, 1996; Stolz & Besner, 1999) which states that semantic activation depends upon the availability of attentional resources directed specifically towards the semantic level of information. When attention is directed towards the orthographic level of information, this occurs at the expense of activation at the semantic level, which results in a relative reduction of priming. Of course, neither the LDT nor the ocular recognition task with dissimilar foils inherently required participants to direct their attention towards semantic-level information, which calls into question why these tasks should show priming at all. However, in the absence of a task goal that is specifically non-semantic, attention may tend towards semantics in a default manner, or because the activation of semantic information can indirectly facilitate task performance. For example, the (in)ability to activate a word's meaning provides a reliable cue to lexical status, and meaningful stimuli are easier to encode and recognize than meaningless visual or orthographic patterns. Together, these results suggest that priming may *seem* relatively task invariant because in the absence of a specifically non-semantic processing goal, attention will default towards semantic information to facilitate word recognition, and this, given enough time, results in priming. Future work will be able to further investigate the role of attention in semantic priming. While the orthographically similar foils have shown that attention may be directed *away* from semantic information, other tasks may be able to direct attention *towards* it. For example, the ocular recognition task could be adapted to use foil probes that are semantically related to the words in the trial set, which should result in stronger priming. Further, specific probe questions may be able to direct attention towards a subset of semantic features, including perceptual features such as color (Yee, Ahmed, & Thompson-Schill, 2012), shape (D'Arcais, Schreuder, & Glazenborg, 1985; Pecher, Zeelenberg, & Raaijmakers, 1998; Schreuder, D'Arcais, & Glazenborg, 1984), or size (Hoedemaker & Gordon, 2014), but also non-perceptual attributes such as animacy or category membership (McKoon & Ratcliff, 1995).

Finally, this characterization of priming as a goal-driven, time-based mechanism has important consequences for the studies of priming that operate within the automatic-strategic framework. Studies of isolated word recognition often take care to use paradigms designed to reduce the opportunity for strategic processes such as expectancy generation or postlexical semantic matching, for example by using short SOA or a low proportion of related trials (McNamara, 2005). Based on our results, it may be equally or even more important to independently consider effects across the response time distribution, as slower responses are more likely than short responses to reflect the influence of task-specific, goal-driven behavior.

Semantic Priming is a Relatively Slow-Acting Mechanism

Unlike manual responses in isolated word-recognition tasks, ocular responses in our study did not show reliable effects of priming in the fast tail of the distribution. We proposed that these discrepant patterns of distributional priming might be due to differences in the response time mapping between ocular and manual responses to word recognition. Specifically, we hypothesized that priming most strongly affects the L2 stage of lexical processing, and as a result should affect fixation durations on the post-target rather than the target word. We did not find strong evidence in support of this hypothesis. It is possible that our particular experimental set up was unsuited for detecting a reliable preview-by-relatedness interaction on the post-target word. As discussed, the use of unequal display characteristics between preview conditions in Experiment 4 may have been disruptive to normal reading, introducing too much variability to detect a subtle foveal-on-parafoveal effect. Experiment 5 equated the display characteristics between letter-identity and nonword-preview conditions, but the concurrent, counterbalanced manipulation of preview on both the target and post-target word may have introduced a large amount of variability masking potential effects.

However, Experiment 5 did show a reliable foveal-on-parafoveal effect of word frequency, demonstrating that the experiment was powerful enough to detect an interaction between ease of processing on the target word and parafoveal preview benefit on the post-target. Therefore, our findings may indicate that L2 effects cannot be clearly dissociated from those affecting L1. The EZ Reader model produces the specific prediction that characteristics of the fixated word ($word_n$) that only affect word reading times on $word_n$ can be inferred to affect only the L1 processsing stage, while characteristics of $word_n$ that affect reading times on the following word ($word_{n+1}$) can be inferred to influence the duration of L2 (Reingold, 2003; Reingold & Rayner, 2006; Wang & Inhoff, 2010; Drieghe, 2008). Thus far, there has been empirical evidence that visual quality modulates processing difficulty of $word_n$ without having an effect on reading times on $word_{n+1}$. Consequently, visual quality is thought to affect the duration of the L1 stage, but any difficulty related to the visual analysis is resolved by the end of the L1 stage and visual quality has no effect on the duration of L2. However, most variables known to affect word recognition difficulty have been shown to affect reading times on both $word_n$ and $word_{n+1}$, suggesting that they affect both stages of lexical processing. For example, word frequency is hypothesized to play an important role in the L1 stage (Reichle et al., 1998; Pollatsek et al., 2006) and word frequency effects on $word_n$ are extremely robust (e.g., Balota & Chumbley, 1984; Rayner & Duffy, 1986; Rayner, 1998), but word frequency also has a reliable effect on reading times for $word_{n+1}$, such that parafoveal preview benefit is reduced in cases when $word_n$ is low frequency (Henderson & Ferreira, 1990; Kennison & Clifton, 1995; Rayner & Duffy, 1986; Rayner et al., 1989). This foveal-on-parafoval effect of frequency suggests that in addition to its effect on L1, word frequency must *also* affect the duration of the L2 stage (Reingold, 2003). To date, there have been no demonstrations of word characteristics affecting only the L2 processing stage, so perhaps this type of dissociation is simply not possible.

Therefore, EZ Reader may not be able provide an account of why fast ocular responses do not show reliable priming while fast manual responses do. Instead, an alternative account may be built based on differences in the response time floor of ocular and manual responses. Across studies using manual LD responses, the average response time in the fastest bin is typically reported to be between 400 and 500 ms (Balota et al., 2008; Yap et al., 2012; De Wit &

Kinoshita, 2014; 2015). In the ocular LDT, the fastest bin had a baseline response time (average response time in the unrelated condition) of 266 ms (Hoedemaker & Gordon, in press) and 312 ms (Experiment 2). In the ocular recognition tasks, average baseline responses in the fastest bin were 243 ms (dissimilar foils, Experiment 1) and 267 ms (similar foils, Experiment 3). Ex-Gaussian distribution fits cannot determine exactly at which point the response distributions for related and unrelated targets begin to diverge, but we can determine the average response time for the first bin to show a priming effect greater than a (somewhat arbitrary) cutoff of 10 ms. Across experiments in the current study, priming first reached 10 ms for bins with average response times of 340 ms (Ocular LDT, Hoedemaker & Gordon, in press), 312 ms (ocular LDT, Experiment 2), 351 ms (ocular recognition with dissimilar foils, Experiment 1), and 513 ms (ocular recognition with similar foils, Experiment 3). While this is a rough and decidedly post-hoc assessment, these numbers suggests that under normal circumstances (i.e., excluding the experiment with similar foils) it may take roughly 300 ms for semantic information to reliably affect word reading times. In contrast, survival curves have shown that word frequency information affected first-fixation duration as early as 145 ms in cases under normal (valid preview) reading conditions, and as early as 256 ms in cases where preview was masked (Reingold et al., 2012). As even the fastest manual response times take approximately 400 ms, the majority of manual responses in isolated word recognition will be slow enough to last beyond the 300 ms minimum necessary to show priming. In contrast, a sizeable portion of ocular responses take less than 300 ms, and for that reason do not allow enough time for priming to take place. This account also provides a possible explanation for the finding that priming is robust during isolated word recognition tasks but not sentence reading. Word recognition times during sentence reading typically range between 200-350 ms (e.g., Balota et al., 2007; Balota &

Chumbley, 1984; Inhoff, 1984; Morris, 1994; Rayner, 1998), so that the fixation durations on most words are shorter than threshold for priming as identified by the current project.

Future research will need to more carefully determine how quickly after the onset of fixation semantic information can reliably affect word recognition times (e.g., by using survival analyses, see (Reingold et al., 2012; Reingold & Sheridan, 2014). In addition, it will be important to determine the extent to which fast reading times reflect the same depth of lexical processing as slow responses. On the one hand, it is possible that some words can be accurately recognized very quickly, for example because they are highly familiar to the reader. On the other hand, it is possible that very fast responses in the ocular recognition tasks simply reflect accurate guesses. The current data provide some evidence that fast responses reflect accurate word recognition rather than guesses, at least to the same degree as manual response tasks. In the ocular LDT, we observed a bias to response 'word,' such that error rates were higher for nonwords than for words, but manual LDs for the same words in the ELP showed a similar bias such in the form of comparable word and nonword error rates. In addition, we found no relationship between individuals' nonword error rates and the extent to which the effect of relatedness within participants was expressed in differences in either μ or τ. Therefore, participants who adopted conservative strategy, more often delaying responses until the word had been fully recognized, did not show greater μ-based priming than participants who adopted a 'risky' strategy, more often responding before words were sufficiently recognized, or vice versa. Finally, incorrect eye movement responses (i.e., moving one's eyes from a nonword onto to the next letter string) on average were slower than correct eye movement responses (i.e., moving one's eyes from a word onto the next letter string). This observation suggests that incorrect classifications of nonwords as words were not due to oculomotor factors, such as an inability to suppress involuntary forward saccades, which might have resulted in very fast, incorrect eye movements. Unfortunately, similar assessments cannot be applied to the ocular word recognition task, as response times on this task do not provide a direct measure of the extent to which each word is successfully encoded. However, the high overall accuracy rate observed in this task suggests that most words were encoded accurately. Future work may be able to further investigate the extent to which fast response times across both types of ocular response tasks reflect full word recognition by manipulating the speed-accuracy tradeoffs of the task, and by assessing how the effects of various lexical variables (e.g., word frequency, orthographic neighborhood size) vary in strength as a function of response speed.

The hypothesis that semantic relatedness information affects online word recognition times in a relatively slow manner is consistent with most of the existing knowledge of eye movements during sentence reading. Fixation duration is reliably affected by word length (e.g., (Brysbaert & Vitu, 1998; Just & Carpenter, 1980; Rayner & McConkie, 1976), word frequency (e..g, Inhoff, 1984; Rayner, 1998), and orthographic neighborhood size and frequency (e.g., (Grainger, O'Regan, Jacobs, & Segui, 1989; Pollatsek, Perea, & Binder, 1999; Williams, Perea, Pollatsek, & Rayner, 2006), and each of these variables operates at the orthographic or perhaps lexical level of word recognition. Irrespective of their specific implementations, most prominent models of word recognition during reading propose that activation of orthographic and lexical information occurs before the activation of semantic information (Reichle et al., 1998; Pollatsek et al., 2006; Engbert, et al., 2005), such that orthographic and lexical effects on reading times should exert are more rapid effect on behavior than semantic effects. One exception to this rule is the effect of sentential predictability, which shows that words that are highly predictable within the context of the sentence are more likely to be skipped (Balota, Pollatsek, & Rayner, 1985;

Ehrlich & Rayner, 1981; Frisson, Rayner, & Pickering, 2005). This suggests predictability affects relatively early processing stages even though its effect is arguable related to the semantic level of processing. However, contextual constraint builds up gradually as the sentence unfolds, rendering some words more predictable than others in a graded fashion. As a result, the predictability of an individual word is fully determined *before* the reader reaches the word, and incoming information at any level can be tested against the prediction or contextual fit. In contrast, semantic relationships between two individual words in a sentence cannot be detected until the second, related word has been accessed, so any processing advantage resulting from local word-word relationships does not benefit from the same gradual build up as the effect of sentence context.

Finally, the time-based account of semantic priming generates the testable prediction that manipulations that slow down word reading times will result in greater priming even in the fast tail of the distribution. To some extent, this effect can be observed when comparing the priming effect in the fastest bin of the ocular LDT between Hoedemaker and Gordon (in press) and Experiment 2. Hoedemaker and Gordon used targets that on average were slightly higher in frequency than the targets in Experiment 2 (3.56 vs 3.12 per 51 million (Brysbaert & New, 2009)), so average baseline response times in the fastest bin were slightly faster (266 ms vs 312 ms), and the smallest distributional priming effect was smaller (2 ms vs 11 ms, respectively). Future studies will be able to test this hypothesis by slowing down word reading times using word-external manipulations such as speed-accuracy tradeoffs or nonword difficulty, or word-internal manipulations such as word frequency or orthographic neighborhood size.

CONCLUSION

Semantic priming has a robust effect on word recognition, affecting both manual and ocular responses across variety of tasks, including those that require a metalinguistic judgment and tasks that simply require words to be encoded for comprehension and memory. Although researchers have tried to specify the nature of meaning-based relationships and priming, experience-based association consistently emerges as the strongest and more reliable predictor of priming during word recognition, and the current study is no exception to this rule.

We have characterized meaning-based priming as a mechanism that allows for the flexible use of prime-target relatedness information to facilitate lexical access in cases where target processing is more effortful. This effect was not specifically associated with the requirement to make a word-nonword decision, suggesting that, given enough time, prime information affects the word recognition rather than the decision or response selection stage of performance. In addition, semantic relatedness effects appear to have a relatively high activation floor, such that word recognition responses faster than 300 ms are unlikely to be affected by semantic prime-target relationships. This time-based account of priming explains differences in distributional priming effects between manual and ocular responses, as well as the fleeting nature priming effects during sentence reading. Importantly, the magnitude of the semantic priming effect is not fully determined by response speed alone, but also depends on the availability of attentional resources. In the absence of a specifically non-semantic processing goal, attention will default towards semantic information to facilitate word recognition, resulting in the observed effort-based pattern of priming. However, when task-related processing goals direct attention towards non-semantic information, semantic priming is reduced relative to baseline response speed.

If we consider semantic priming as a mechanism that primarily operates in cases where word recognition is effortful, it is perhaps not surprising that associative relationships provide the strongest account of priming. Associative relationships are extremely flexible, such that readers may be able to find relationships between any two concepts on the fly, whereas specific semantic relationships are much more fixed. In cases where word recognition is difficult, relevant associative relationships are most easily accessible to the reader and thus most likely to be recruited online in service of the word recognition process.

APPENDIX: STIMULI

Synonyms		Antonyms		Otherwise-Associated	
PRIME	TARGET	PRIME	TARGET	PRIME	TARGET
foggy	unclear	ending	beginning	airport	plane
mischief	trouble	goodbye	hello	blackboard	chalk
foundation	base	once	never	blanket	warm
concern	worry	pull	shove	century	year
purpose	reason	victim	murderer	cobra	snake
alter	change	construct	destroy	compulsion	obsession
community	neighborhood	hungry	full	danger	scary
demon	devil	stand	fall	electrician	wire
myth	legend	mend	break	interrupt	rude
violet	purple	move	stay	torch	fire
gorgeous	beautiful	opposite	same	homework	study
contemporary	modern	float	sink	tuba	instrument
roam	wander	loss	gain	safari	jungle
adorable	cute	relax	tense	whiskey	booze
journal	diary	thick	thin	cookbook	recipe
marsh	swamp	expert	novice	astronaut	space
simple	easy	reject	accept	europe	asia
defrost	thaw	public	private	secretary	boss
combination	mixture	solution	problem	compass	direction
blame	accuse	part	whole	balcony	ledge
pile	stack	student	teacher	wings	bird
dish	plate	basement	attic	chemistry	science
courage	bravery	frown	smile	clarinet	flute
vote	elect	failure	success	angel	heaven
teenager	adolescent	fake	real	spring	summer
rush	hurry	finish	start	mammal	whale
characteristic	trait	deep	shallow	disaster	earthquake
choice	decision	learn	teach	lettuce	tomato
sale	bargain	rough	smooth	mars	planets
small	little	guilty	innocent	mute	deaf
helper	assistant	death	life	celery	carrot
weird	strange	above	below	angle	geometry
middle	center	best	worst	relative	aunt
pick	choose	closing	opening	cauliflower	broccoli
boring	dull	winner	loser	washcloth	towel
loving	caring	buyer	seller	thief	steal
careful	cautious	borrow	lend	hands	feet
garbage	trash	white	black	quench	thirst
dinner	supper	tight	loose	lobster	crab
disappear	vanish	more	less	smell	taste

hero	superman
emergency	ambulance
prickly	cactus
child	baby
goal	achieve
image	mirror
language	english
honest	truth
congress	senate
drug	cocaine
glass	window
lizard	reptile
meat	steak
cents	dollars
court	judge
lion	tiger
artery	vein
toilet	bathroom
egypt	pyramid
minutes	hours
silk	satin
clam	oyster
pain	headache
flower	rose
knife	fork
weather	climate
conditioner	shampoo
house	brick
embarrass	blush
lime	lemon
beard	mustache
write	print
pancakes	syrup
hear	listen
armor	knight
army	navy
volcano	erupt
noun	verb
duck	quack
lightning	thunder

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