A Fresh Look on Semantic Priming Effects

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Table of Contents

Thesis Abstract

Responses to words (targets) are faster when they are preceded by a word (the prime) related in meaning compared to when the preceding word is semantically unrelated (e.g., RT for *hawk–EAGLE* < *table–EAGLE*). This semantic priming effect is widely believed to be automatic when the time between the onset of the prime and target is short, generally less than 250 ms, and is generally explained in terms of *automatic spreading activation*. The research presented in this thesis examined the assumption of automaticity of semantic priming effects, through the manipulation of the proportion of related prime–target pairs (relatedness proportion, RP), prime visibility (masked vs. unmasked), and type of task (lexical decision vs. semantic categorization). In addition to the analysis of mean RT, the effect of these three manipulations on the RT distribution was also examined. Contrary to the assumption that semantic priming at a short SOA is automatic, all three manipulations impacted on the size of the semantic priming effect and produced different RT distribution patterns. These findings are used to reconsider the notion of automatic spreading activation in explaining semantic priming effects at short SOAs. An alternative view in which semantic priming effects are explained in terms of task-dependent processes is proposed.

Declaration

I certify that the research presented in this thesis entitled "**A Fresh Look on Semantic Priming Effects**" has not previously been submitted for a degree nor has it been submitted as part of requirements for a degree to any other university or institution other than Macquarie University.

In addition, I certify that this thesis is my original work that was conducted at the Department of Cognitive Science under the supervision of my principle supervisor Sachiko Kinoshita. All information sources and literature used are indicated in the thesis.

The research presented in this thesis was approved by Macquarie University Ethics Review Committee (HE24NOV2006-R04946 and 5201200035).

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Chapter 1—Introduction

Introduction

In reading, semantic context plays an important role. This is demonstrated in the laboratory by the *semantic priming effect* (Meyer & Schvaneveldt, 1971, for reviews see McNamara, 2005; Neely, 1991). The semantic priming effect refers to the finding that the decision to a word (e.g., “Is this a word?” or “Is this a living thing?”) is facilitated, that is, made faster and more accurate, when the to-be-processed word (the target) is preceded by a semantically related word (the prime, e.g., *hawk*–*EAGLE*) compared to when the preceding word is unrelated in meaning (e.g., *chain*–*EAGLE*).

A major theoretical framework that explains semantic priming effects is the two-process model (Neely, 1976; 1977; Posner & Snyder, 1975). According to this framework, semantic priming effects can be produced by one of two processes; one automatic, termed the automatic spreading activation process, and the other attentional/controlled process, termed the conscious prediction or expectancy generation strategy. Both are assumed to operate within the lexical/semantic network, in which concepts are represented as interconnected nodes, and the relatedness between two concepts reflected in the length of the link between two nodes. According to the automatic spreading activation process, when a node is activated, its activation spreads automatically along links to other, related nodes, with the activation decaying across distance and with time. A target (e.g., *EAGLE*) therefore receives greater activation from a related prime (e.g., *hawk*) than from an unrelated prime (e.g., *chain*), facilitating its recognition (Collins & Loftus, 1975). According to the expectancy generation process, when participants notice that prime and target can be semantically related, they use a limited-capacity attentional system to generate expectancies regarding the target’s identity based on the prime’s semantic properties; When the target is part of the expectancy set, the response to the target will be facilitated (e.g., Becker, 1980; Neely, 1977).

The two-process model thus posits that semantic priming effects can be produced by either the automatic spreading activation process or the conscious expectancy strategy, and which process is responsible for the effect depends on the stimulus-onset asynchrony (SOA) between prime and target. Whereas the automatic spread of semantic activation is assumed to be fast-acting, it is assumed that it takes time (generally more than 400 ms) to generate expectancies (Neely, 1991; Posner & Snyder, 1975; see Hutchison, 2007, for a review). Hence at short prime–target SOAs (generally less than 250 ms), when there is insufficient time for expectancies to be generated, semantic priming effects are only attributable to the fast-acting spreading activation process, and therefore considered to be automatic.

What Does it Mean for Semantic Priming to be Automatic?

Although the view that semantic priming effects obtained at short SOAs reflect an automatic spreading activation process is widely accepted in the literature, a closer look at this claim is warranted in terms of what it means for a process to be automatic. In addition to the assumption that an automatic process is fast-acting, automatic processes are generally assumed to contain the following features: 1) occur without intention, 2) capacity-free, 3) uncontrollable or involuntary, and 4) occur without conscious awareness (Moors & De Houwer, 2006; Neely & Kahan, 2001; Posner & Snyder, 1975). Although the semantic priming literature has found much empirical support for some of the features of automaticity, others have received mixed support, as will be reviewed below.

Automaticity: "Occur Without Intention" & "Capacity-Free"

The view that semantic priming effects at short SOAs reflect processes that "occur without intention" has received support from the pioneering work by Neely

(1977). In his study, participants carried out lexical decisions to targets preceded by a category name prime ("*BIRD*", "*BUILDING*", "*BODY*") presented at a short (250 ms) to long (2,000 ms) SOA. The SOA manipulation was crossed with the "shift" manipulation, which was designed to separate the semantic relatedness of prime and target from the intentional generation of expectancies. In the non-shift condition, participants were instructed to use the category prime to predict a member of the same category (e.g., if the prime is *BIRD*, predict a bird-exemplar, for example *robin*). In this condition, a target could either be related (e.g., *BIRD–robin*) or unrelated (e.g., *BIRD–arm*). In contrast, in the shift-condition, participants were instructed to shift their attention and use the category prime to predict a member of another specified category (e.g., if the prime is *BODY*, predict a building-exemplar, for example *door*). In this condition, a target could be either expected and unrelated (e.g., *BODY–door*), unexpected and unrelated (e.g., *BODY–sparrow*), or unexpected but related (e.g., *BODY–heart*). On the assumption that the spread of semantic activation "occurs without intention", it was expected that semantically related primes would produce facilitation regardless of whether the related target was expected or unexpected. In line with this assumption, at the short SOA, which is generally assumed to be too short for intentional processes to kick in, the shift manipulation did not affect the spread of semantic activation; semantic priming effects were observed for both the expected and unexpected related prime–target pairs. In contrast, at the longer SOAs, in which strategically, controlled processes are assumed to be at play, only those items that were from the expected category produced semantic priming effects.

Second, from the view that automatic processes are "capacity-free", they should not consume attentional resources and hence a divided attention manipulation should not affect the size of semantic priming effect. This prediction has been investigated through the manipulation of task-load (e.g., performing a secondary task concurrently) and spatial attention (e.g., presenting a word in an unattended location). This literature, with a specific focus on the semantic priming effect in the Stroop colour naming task and the lexical decision task, was critically reviewed in Neely and Kahan's (2001) re-evaluation of the automaticity of semantic activation. In brief, their conclusion was that while there are demonstrations that these manipulations can reduce the size of the semantic priming effect (e.g., Fuentes, Carmona, Agis, & Catena, 1994), it is unclear whether the semantic priming effect observed was expectancy-based, and hence they do not constitute evidence against the automaticity of semantic activation.

In sum, there is wide acceptance for the view that semantic priming effects obtained at short SOAs reflect an automatic process, based on the studies that investigated the "occur without intention" and "capacity-free" features of automaticity.

Automaticity: "Uncontrollable or Involuntary" & "Occur Without Conscious Awareness"

In contrast to the above, when turning to the other features of automaticity—namely, "uncontrollable or involuntary" and "occur without conscious awareness"—the support for the view that semantic priming effects at short SOAs are driven by an automatic process is more mixed.

First, from the view that the spread of semantic activation is "uncontrollable or involuntary", semantic priming should not be under strategic control and therefore cannot be regulated. This means that semantic priming should occur to the same degree regardless of the extent to which the prime is useful, or the type of task used. The controllability of semantic priming has typically been tested by manipulating the usefulness of the prime through a change in the proportion of related prime–target pairs in the experiment, termed the *relatedness proportion* (*RP*; e.g., Tweedy, Lapinski, & Schvaneveldt, 1977). Consistent with the view that semantic priming effects at short

SOAs are produced by an automatic process that is “uncontrollable”, a number of reviews have concluded that RP has little or no impact on the magnitude of the semantic priming effect at short SOAs (e.g., Hutchison, 2007; Hutchison, Neely, Johnson, 2001, Neely, 1991). Against this however, there are studies—most notably by De Groot (1984)—in which robust RP effects were reported at a short SOA.

One important point to note in examining these mixed reports is the use of the lexical decision task, as in De Groot’s (1984) study. There has been a growing recognition that the use of a short SOA in the lexical decision task does not warrant that semantic priming effects reflect only the automatic spreading activation process. In the lexical decision task, an alternative strategic process may come into play, that due to its retrospective nature—it is not operational until after the target has been presented—is not precluded by the use of a short SOA (De Groot, 1984). This process will be discussed in more detail in the following section, and for now I will note that this alternative process may explain why semantic priming has not been found to be “uncontrollable or involuntary”.

Turning to the notion that the spread of semantic activation can “occur without conscious awareness”, semantic priming should occur even when the prime cannot be consciously identified, that is, masking the prime should not impact on the occurrence of the semantic priming effect. Although masked semantic priming effects have widely been regarded as strong evidence for the automaticity of semantic activation, the empirical status of masked semantic priming effects is in fact notoriously mixed (see e.g., Holender, 1986; Kouider & Dehaene, 2007, for reviews). In contrast to semantic priming effects obtained with unmasked (visible) primes, which have generally been found to be reliable at short SOAs (e.g., Neely, 1991), as will be discussed shortly, masked semantic priming effects have typically been weak and unreliable. This elusiveness of masked semantic priming effects has raised doubt regarding the notion that semantic priming can "occur without conscious awareness".

In sum, automaticity has generally been assumed to have multiple features. In the semantic priming literature, some features of automaticity have received much empirical support, for other features however, the support has been more mixed. Specifically, in contrast to the "occur without intention" and "capacity-free" features of automaticity, the evidence for the automaticity of semantic priming in terms of the "uncontrollable or involuntary" and "occur without conscious awareness" features has been less convincing.

Chapter Outline

The goal of this thesis is to reconsider the notion that semantic priming effects at short SOAs reflect the workings of an automatic spreading activation process. Specifically, I will focus on two key characteristics assumed of an automatic process, the "uncontrollable or involuntary" feature, and the "occur without conscious awareness" feature. To this end, I will examine how semantic priming effects obtained at a short SOA (240 ms) are impacted by three manipulations: 1) RP, that is, the proportion of related prime–target pairs in the experiment, 2) the visibility of the prime (masked vs. unmasked primes), and 3) the type of task used (lexical decision vs. semantic categorization).

In the following sections of this chapter, I will outline how these manipulations will be used to investigate the automaticity of semantic priming. I will start by providing a more detailed review of the literature of semantic priming studies that manipulated RP in order to justify the use of this manipulation in the semantic categorization task (to be used in Chapter 2) and the lexical decision task (to be used in Chapter 3). Then I will review the literature of semantic priming studies that used masked primes in order to justify the manipulation of prime visibility in both the semantic categorization and lexical decision task (to be investigated in Chapter 4). In the final section of this chapter, I will introduce the tool of RT distribution analysis and outline how this tool will be used as a magnifying glass to explore the processes responsible for semantic priming effects in this thesis.

Semantic Priming and the Manipulation of Relatedness Proportion

The first goal of this thesis is to examine the notion that semantic priming at short SOAs is “uncontrollable and involuntary” by exploring the role of strategic control through the manipulation of RP, that is, the proportion of related prime–target pairs (e.g., *hawk*–*EAGLE*) in the experimental list. To this end, the size of the semantic priming effect obtained in two different RP conditions will be compared, one in which prime–target pairs were related on 25% of all trials of the experiment, and one in which prime–target pairs were related on 75% of all trials, in the semantic categorization task (Chapter 2) and the lexical decision task (Chapter 3).

Using a lexical decision task, Tweedy, Lapinski, and Schvaneveldt (1977) were the first to test the effect of RP on semantic priming and found that the size of the semantic priming effect was greater when RP was high compared to when it was low. They termed this the *relatedness proportion effect* (*RP effect*). Tweedy et al. interpreted the RP effect as a marker of strategic processing. Specifically, participants use the expectation generation strategy (Becker, 1980; Neely, 1977) adaptively. When RP is high, participants are more likely to use the semantic properties of the prime to predict the identity of the upcoming target as it results in correct predictions on a large number of trials. In contrast, when RP is low, that is, when the prime and target are unrelated on most trials, the use of the expectancy generation strategy would result in incorrect predictions on a high proportion of trials.

In line with the assumption that it takes time to generate expectancies, reliable RP effects have generally been found only at long SOAs (those greater than 250 ms; e.g., Hutchison, 2007; Hutchison, Neely, & Johnson, 2001). From his review of 24 studies using the lexical decision task and the pronunciation (read-aloud) task that manipulated both RP and SOA, Hutchison (2007) concluded that RP impacted on the size of the semantic priming effect "only when the SOA is long enough for participants to consciously generate likely targets" (p. 646). While Hutchison was careful to point out that the use of an expectancy generation strategy is not all-or-none, and the time taken to generate expectancies is modulated by individual differences, the general absence of the strategic RP effect at SOAs of 250 ms or less (short SOAs) has widely been taken as evidence that semantic priming at short SOAs is free from strategic influences and thus automatic.

De Groot's (1984) study, however, stands in contrast to this conclusion. Manipulating RP at three different SOAs (240 ms, 540 ms, and 1,040 ms), she reported reliable RP effects at all three SOAs. The significance of the RP effect at the short SOA (240 ms) is unexpected from the view that at this short SOA, only the automatic spreading activation process is responsible for semantic priming effects. De Groot attributed the result to an additional strategic process termed *post-lexical coherence checking* (De Groot, 1984), a process that due to its retrospective nature can influence semantic priming effects at long as well as short SOAs. Consistent with the terminology used by Neely and Keefe (1989), this process will be referred to as the *retrospective semantic matching strategy* in this thesis.

Retrospective Semantic Matching in the Lexical Decision Task

In the retrospective semantic matching strategy, after the target is presented but before a decision is made, the target's meaning is matched to that of the prime and the assessed relationship between prime and target used as a basis for making the decision to the target. In the lexical decision task, the decision required to the target is whether it is a word or a nonword. With the exception of a few studies (e.g., Antos, 1979; Norris, 1984), typically, word primes paired with nonword targets are selected to be semantically unrelated to the word that the nonword resembles (e.g., a pair like *father-MOHTER* is avoided). The semantic relatedness of the prime and target can thus be used as an indicator of the target's lexical status: If the prime and target are semantically related, the target must be a word; if the prime and target are unrelated, the target is likely to be a nonword. The viability of the retrospective semantic matching strategy is bound to the *nonword ratio*, that is, the proportion of trials on which the target in a semantically unrelated prime-target pair is a nonword target relative to a word target (e.g., if 75 word targets are preceded by an unrelated word prime, and all 100 nonword targets are preceded by an unrelated word prime, the nonword ratio is 100/(100+75)= .57). When nonword ratio is high, meaning that the target in an unrelated prime-target pair is a nonword on most trials, the absence of a semantic relationship between prime and target is a more reliable indicator that the target is a nonword compared to when nonword ratio is low.

As pointed out by Neely, Keefe, and Ross (1989), nonword ratio is typically confounded with RP. When RP is high, by definition, a low proportion of word targets are preceded by semantically unrelated primes. Consequently, the proportion of trials on which the target is a nonword given an unrelated word prime is also high (provided the number of word and nonword targets is held constant); that is, it results in a high nonword ratio. For example, consider a lexical decision experiment containing 100 word targets and 100 nonword targets, all preceded by word primes. With an RP of .75, the nonword ratio would 100/(100+25) = .80. With an RP of .25, the nonword ratio would be 100/(100+75) = .57. Neely et al. (1989) investigated the effect of nonword ratio on the size of the semantic priming effect by manipulating nonword ratio independently from RP. They found that the size of the semantic priming effect was greater when nonword ratio was high compared to when nonword ratio was low, even when RP was held constant. Neely et al. concluded that RP effects in lexical decision typically reflect the influence of both the expectancy generation and retrospective semantic matching strategies, with the RP manipulation modulating the use of expectancy generation and nonword ratio modulating the use of retrospective semantic matching. From this perspective, the RP effect observed by De Groot (1984) at a short SOA can be explained as a nonword ratio effect, driven by the retrospective semantic matching strategy (and indeed, this is how De Groot interpreted her finding). Due to its retrospective nature (the relationship between prime and target is not assessed until *after* the target is presented), this strategy is not precluded by the use of a short SOA.

The Semantic Categorization Task: Automatic Semantic Priming?

The possibility of the retrospective semantic matching strategy means that semantic priming effects obtained at short SOAs in the lexical decision task cannot be interpreted solely in terms of an automatic spreading activation process. To rule out this strategy in the lexical decision task, the confound between the manipulation of RP and nonword ratio needs to be removed, and separating these two requires a very large number of filler trials (Neely, et al., 1989), which may create other confounds such as practice or fatigue effects. However, the strategy can be precluded in a task that does not require a word–nonword discrimination: The semantic categorization task. In this task, the decision required to the target is whether it is a member of a specified category (e.g., "Is the target an animal?"). In contrast to the lexical decision task, semantic relationship between prime and target can be easily separated from the decision, by equating the proportion of related trials for the exemplar and non-exemplar targets. In this way, the presence or absence of a semantic relationship between prime and target would not be indicative of the target's membership in the semantic categorization task (McRae, de Sa, & Seidenberg, 1997).

Combining the use of a semantic categorization task with the use of a short SOA should thus preclude both the retrospective semantic matching and the expectancy generation strategies, and ensures semantic priming effects are only attributable to the automatic spreading activation process. Under these conditions, the manipulation of RP provides a straightforward test of the "uncontrollability" of the spreading activation process. Whether RP impacts on the size of the semantic priming effect when a short SOA is used in a semantic categorization task will be investigated in Chapter 2. To explore the notion that semantic priming effects are driven by different processes in the semantic categorization and lexical decision tasks, the same prime-target pairs and RP manipulation that were used in Chapter 2 will be used in a lexical decision task in Chapter 3.

Semantic Priming and the Manipulation of Prime Visibility

The second goal of this thesis is to examine the assumption that semantic priming "can occur without conscious awareness" through the manipulation of prime visibility. To this end, in Chapter 4, semantic priming effects obtained with masked primes will be compared to those obtained with unmasked primes, using both the lexical decision and the semantic categorization task.

Thirty years ago, Forster and Davis (1984) developed the masked priming paradigm, in which the prime is presented for a very brief duration (typically 50 ms or less), preceded by a forward mask (generally consisting of hash signs; i.e., ####). And immediately followed by the target, which serves as a backward mask to the prime. This three-field masking procedure makes the onset of the prime difficult to detect and prevents conscious identification of the prime, thereby precluding strategic use of the prime. Due to the minimal awareness of masked primes, masked priming effects have often been viewed as a marker of automatic, non-strategic processing. Indeed, Neely (1991), in his comprehensive review of semantic priming effects in visual word recognition tasks, has argued that the finding of subliminal priming effects is "one of the strongest pieces of evidence supporting an automatic spreading activation account of priming" (p. 297). However, in contrast to the highly robust semantic priming effects found with visible (unmasked) primes, findings of masked semantic priming effects are more mixed, as will be reviewed in Chapter 5. This general elusiveness of reliable masked semantic priming effects reported in these earlier studies (e.g., Holender, 1986; Stolz & Besner, 1999; see Kouider & Dehaene, 2007, for a historic review) has raised doubt regarding the automaticity of the spreading activation process.

Masked Semantic Priming: Two important conditions

Against the earlier literature expressing doubt regarding the empirical status of masked semantic priming effects, Dehaene and colleagues (1998) re-established the finding. This, and other recent studies, revealed two conditions that appear critical for revealing reliable masked semantic priming effects: 1) The task must require a semantic decision (e.g., "Does the number denote magnitude larger than 5?"; "Does the word denote an animal?"), and 2) the semantic similarity of prime and target must be indexed by a large amount of feature overlap instead of mere category congruence.

The Importance of a Semantic Task

In their influential masked semantic priming study, Dehaene et al. (1998) pointed out that masked semantic priming effects can be found when the task performed on the target is also applied to the prime. The finding of a reliable semantic priming effect, also called a *category congruity effect*, was interpreted as support for the notion that masked primes are semantically processed in a semantic decision task. In Dehaene et al.'s study, participants categorized a number target (both as Arabic digits, e.g., 3, 8, and as spelt-out words, e.g., three, eight) as being smaller or larger than 5. Irrespective of the prime and target notation, they were 24 ms faster when the preceding masked prime was category-congruent (e.g., 2–4, two–4, or 2–FOUR) compared to when it was category-incongruent (e.g., 6–4, six–4, 6–FOUR). Moreover, Dehaene et al.'s brain imaging data (fMRI and event-related potentials, ERPs) demonstrated that the congruity effect was reflected as an activity in the motor cortex. On the assumption that a motor response is prepared subsequent to semantic processing and categorizing an item, these results were interpreted as evidence for semantic processing of masked primes. However, the semantic nature of the effect obtained in Dehaene's study was questioned by Damian (2001). Specifically, because exemplars from a small category (single digits) were used, they had to be used repeatedly, both as a prime and target, allowing the formation of an association between a stimulus and a response. Therefore, it is unclear whether the category congruity effect reflected semantic processing of masked primes or learned stimulus-response mapping (Damian, 2001). However, under conditions that controlled for this caveat in Dehaene et al.'s study, subsequent studies that used primes that had not been used as targets—so-called novel primes—did report reliable category congruity effects (e.g., Kunde, Kiesel, & Hoffman, 2003; Reynvoet, Gevers, & Caessens, 2005; see Van den Bussche, Van den Noortgate, & Reynvoet, 2009 for a review). These studies provided compelling evidence that masked primes can be semantically processed in semantic decision tasks.

The Importance of Semantic Feature Overlap

Although the reports of reliable category congruity effects provided support for the view that semantic processing can occur without conscious awareness, these effects were obtained with stimuli from small categories with often a finite set (e.g., "numbers smaller or larger than the number 5"). These small categories are not comparable to the large categories (e.g., "animals", "words") that are typically used in other studies of word recognition (e.g., lexical decision), in which masked semantic priming effects have generally been found to be small and unreliable. Whether reliable masked semantic priming effects can be found with stimuli from large categories (e.g., "animals", "living things") in semantic categorization tasks has been shown to depend on the semantic similarity of prime and target, with prime and target required to share many semantic features (e.g., Bueno & Frenck-Mestre, 2002, 2008; Frenck-Mestre & Bueno, 1999; Quinn & Kinoshita, 2008).

McRae and Boisvert (1998) were the first to point out that under conditions in which strategic use of the prime is precluded and semantic priming effects thus considered to reflect an automatic process, prime–target similarity should be indexed by semantic feature overlap. They pointed out that although prime–target relatedness is often confounded with category congruence in semantic categorization tasks (e.g., *duck–COW* vs. *boot–COW*), category congruence alone does not guarantee that automatic semantic priming effects will be found. Instead, prime–target relatedness should be defined in terms semantic feature overlap (e.g., <has fur>, <has wings>, McRae, et al., 1997; Smith, Shoben, & Rips, 1974). Previous studies (e.g., Lupker, 1984; Shelton & Martin, 1992) had reported that under automatic conditions, semantically related prime–target pairs (e.g., *duck–cow; nose–hand*) did not produce semantic priming effects in the absence of an associative relationship. However, as McRae and Boisvert pointed out, the semantic similarity of the related items used in these studies was not sufficient to produce automatic semantic priming effects; the related prime–target pairs were category congruent (e.g., duck and cow are both farm animals; nose and hand are both body parts), but did not share many semantic features (e.g., a duck flies but a cow does not; a cow produces mild but a duck does not, etc.). With a new set of stimuli, selected to have high semantic feature overlap (selected from McRae et al.'s 1997 feature production norms; e.g., *goose–TURKEY; pillow–CUSHION)*, McRae and Boisvert found a robust semantic priming effect.

Consistent with McRae and Boisvert's findings, Quinn and Kinoshita (2008) demonstrated that only prime–target pairs that share many semantic features produced masked semantic priming effects in their semantic categorization task. Using the large category "animals", Quinn and Kinoshita manipulated semantic similarity by constructing two category-congruent primes that differed in the amount of feature overlap: Semantically related prime–target pairs, selected to share many semantic features (e.g., *hawk–EAGLE*; both <lay eggs>, <have feathers>, etc.) and semantically unrelated pairs, selected to share few semantic features (e.g., *mole–EAGLE*; an eagle <has features>, a mole does not; a mole <has fur>, an eagle does not, etc.). When compared to category-incongruent pairs (e.g., *knee–EAGLE*), semantic priming effects were only found for the semantically related animal targets. This robust semantic priming effect appeared at odds with Forster, Mohan, and Hector's (2003) failure to find a reliable masked semantic priming effect in a similar semantic categorization task. However, considering the semantic similarity of Forster et al.'s related items (e.g., *rabbit–PARROT*) corresponds to Quinn and Kinoshita's semantically unrelated but category-congruent items in terms of feature overlap, the absence of a masked semantic priming effect in their study is readily explained.

Along similar lines, Frenck-Mestre and Bueno (1999, see also Bueno & Frenck-Mestre, 2002; 2008 for similar results) compared masked semantic priming effects for prime–target pairs that were related through semantic feature overlap (e.g., *whale–dolphin*) and prime–target pairs that were related through category congruence and association (e.g., *cow–bull; shirt–pants*; items that mainly reflect word co-occurrence). They reported that at very brief prime durations of 28 and 43 ms, only those prime–target pairs that had a pure semantic relationship produced masked semantic priming effects. Together, these studies clearly demonstrated that for reliable masked semantic priming effects to be found, and when large categories are used, it is essential that prime–target relatedness is indexed by semantic feature overlap rather than category congruence or association. These findings motivated the selection of the prime–target pairs used in this thesis, with primes and targets used in the semantically related condition selected to share many semantic features.

Implications for Semantic Memory Models

The notion that semantic relatedness is determined by semantic feature overlap has implications for how to view the organization of semantic memory. In the automatic spreading activation process, activation is assumed to spread through association in a localist network, in which concepts are represented as unitized "nodes" (Collins & Loftus, 1975). The notion of "shared semantic features" however, is more compatible with a distributed memory model that dispenses the notion of unitized nodes and instead represents concepts as sets of distributed features (e.g., <has fur>, <has a tail>) and the similarity of two concepts as overlapping activation patterns across the feature set (Masson, 1995; Plaut & Booth, 2000). In these models, semantic priming reflects the prime's residual activation. When the prime is related to the target, the prime's activation pattern resembles that of the target and activation of the prime will assist the featural network to settle on the target's pattern of activation faster; hence recognition of the target is facilitated.

Although distributed memory models could account for one of the two conditions that have been identified as critical for masked semantic priming effects to be found—that is, it is critical that the semantic similarity of prime and target is indexed by semantic feature overlap rather than category congruence—its appeal to the notion of *automatic* pre-activation cannot explain why masked semantic priming effects should only arise in tasks that require a semantic judgment to the target (e.g., a semantic categorization task). To explore whether the automaticity assumption of "occurs without conscious awareness" depends on the nature of the task used, the same highly semantically similar prime–target pairs—indexed by semantic feature overlap—were used in Chapter 4 to compare masked and unmasked semantic priming effects in the lexical decision and semantic categorization tasks.

RT Distribution Analysis: A Magnifying Glass

In the literature reviewed so far, semantic priming effects have been assessed as a difference in the mean RT between the related and unrelated prime conditions. It is beginning to be appreciated however, that relying on analyses of mean RT alone may not be informative, and worse, may create a misleading picture of semantic priming (e.g., Balota & Yap, 2011; Balota, Yap, Cortese, & Watson, 2008; Gomez, Perea, & Ratcliff, 2013; Heathcote, Popiel, & Mewhort, 1991). One reason for this is that RT distributions are typically positively skewed, meaning that the RT distribution is asymmetrical with most RTs clustered at the lower end of the RT scale. A sole focus on the mean RT of a positively skewed RT distribution misses important information on how semantic priming is reflected in the RT distribution.

As was pointed out by Pratte, Rouder, Morey, and Feng (2010; also see Spieler, Balota, & Faust, 2000), an experimental manipulation can result in the same effect on the mean RT, but actually be manifested in the RT distribution in three different ways:

1) it can have a constant effect on the whole RT distribution, resulting in an overall distributional shift; 2) it can affect only the tail of the RT distribution, resulting in a change of the skew of the distribution; or 3) it can affect both. Analysing the RT whole distribution, rather than only the mean RT, allows these different effects of experimental manipulations to be captured. This creates a more complete picture of the effect in question (e.g., the semantic priming effect), which has the potential to reveal the nature of the processes underlying the effect. To this end, RT distribution analysis will be used in this thesis to shed light on the processes underlying the semantic priming effect.

Next, I will describe three alternative methods that have been used to capture these different effects of experimental manipulations on RT distributions.

Methods for Capturing the Effects on the RT Distribution

One method is to plot the RT data directly in a quantile plot. Examples of quantile plots are depicted in the left panels of Figure 1. In order to create a quantile plot, RT data for individual participants are ordered from fast to slow for each condition (in the case of semantic priming, the semantically related condition vs. the semantically unrelated condition). The ordered RT data are then divided into, for example, five equal sized portions (RT bins)—called *quantiles*—that contain for example the fastest 20% of trials, the next fastest 20%, and so on. The average of the last trial of the faster quantile and the first trial of the slower quantile make up the quantile estimate, and these quantile estimates are then plotted separately for each condition.[1] The difference between the quantile estimates for the two conditions reflects the semantic priming effect. For ease of visualising the effect of an experimental manipulation on the RT distribution, this

[1] A related method is to plot *vincentiles*, which reflects the average of each RT bin (e.g., the fastest 10%, the next fastest 10% of the ordered RT data, e.g., Ratcliff, 1979). Analyses of quantiles and vincentiles generally yield very similar results (e.g., Jiang, Rouder, & Speckman, 2004).

difference between the conditions (e.g., the semantic priming effect) can also be plotted as a function of quantile. Examples of these "difference" plots are presented in the right panels of Figure 1.

How then, are the different effects of an experimental manipulation reflected in these quantile and difference plots? A distributional shift is reflected in a quantile plot as a constant effect across the quantiles (i.e., a shift of the intercept). An example of this pattern is presented in Figure 1A. The same distributional shift pattern is reflected in a difference plot as a flat line, which is depicted in Figure 1B. An effect on the skew of the RT distribution is reflected in these plots as either an overadditive or underadditive interaction between the effect and quantile. Figures 1C and 1D illustrate the overadditive interaction pattern, in which the size of the effect increases across the quantiles (i.e., a slope difference between the conditions, see Figure 1C). In a difference plot, this overadditive interaction can be reflected as a positively sloped line (see Figure 1D). Figures 1E and 1F depict the underadditive interaction pattern, in which the size of the effect decreases across the quantiles (see Figure 1E), a pattern that is reflected as a negatively sloped line in the difference plot (see Figure 1F).

A third method that can be used to capture the different effects of an experimental manipulation on the RT distribution is fitting the RT distribution to an explicit model of the shape of the RT distribution, for example the ex-Gaussian distribution (e.g., Balota & Yap, 2011). The ex-Gaussian distribution is the convolution (a mathematical combination) of a Gaussian and an exponential distribution and has shown to be a good fit to empirical RT distributions of several tasks (Heathcote, et al., 1991; Ratcliff, 2012).

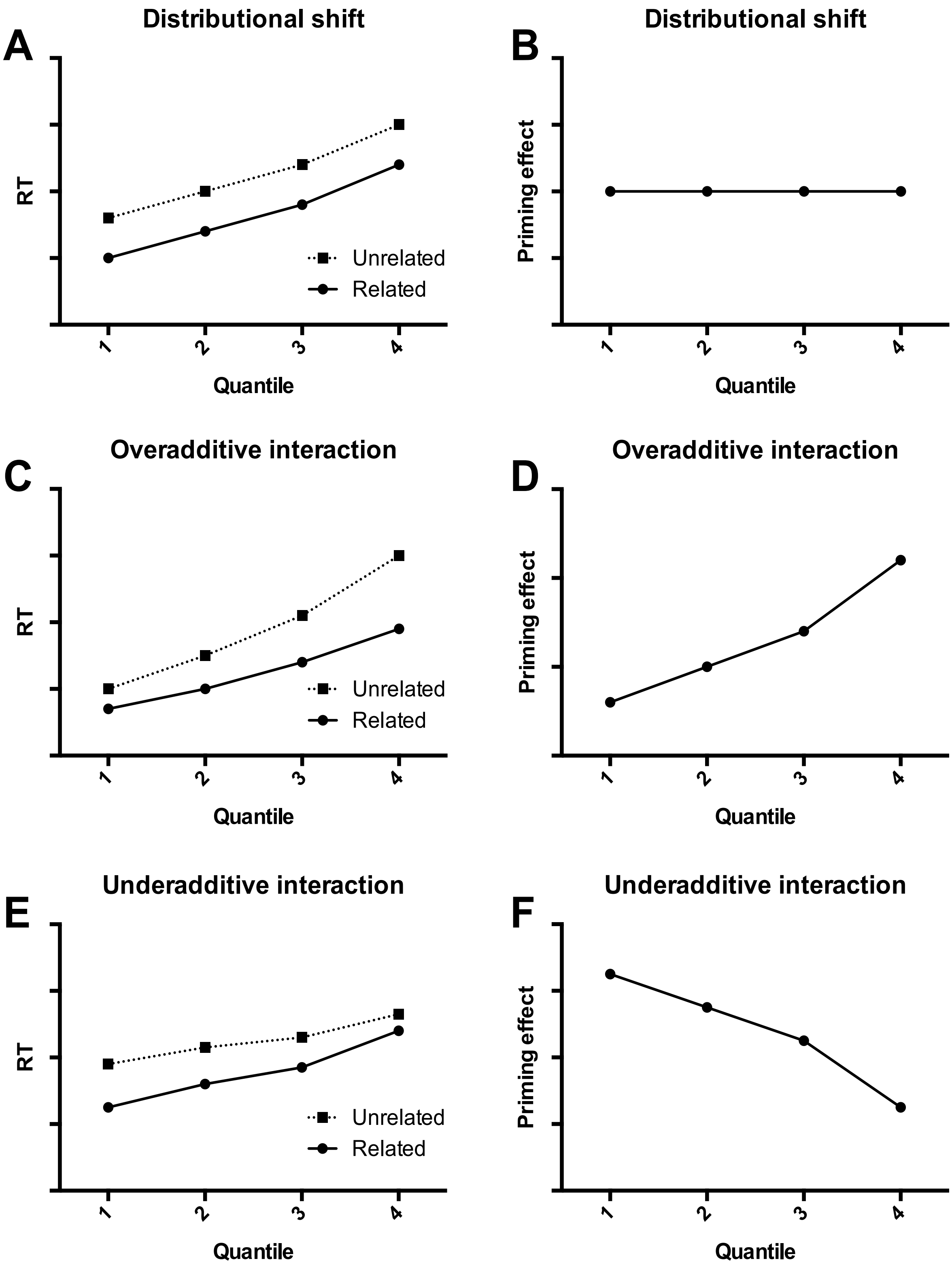

Figure 1. Examples of RT distribution patterns reflecting the effect of prime relatedness on the shift and the skew of the RT distribution in quantile plots (panels A, C, and E, at left) and the difference between the two conditions (reflecting the semantic priming effect) in difference plots (panels B, D, and F, at right).

The ex-Gaussian distribution is summarized in three parameters that capture different aspects of the distribution: μ (mu) and σ (sigma), which reflect the mean and standard deviation of the Gaussian distribution, and τ (tau), which reflects both the mean and standard deviation of the exponential distribution. While some have interpreted these parameters as reflecting different processes (e.g., Hohle, 1965, associated the Gaussian component with motor processes and the exponential component with decision processes), it has been pointed out that caution needs to be taken with mapping parameters onto processes (e.g., Balota & Yap, 2011; Heathcote et al., 1991). Instead, the ex-Gaussian parameters are more safely used as simple summary statistics that can capture the effect of the experimental manipulation on the RT distribution, and this is how they will be used in this thesis. Accordingly, in these parameters, a distributional shift is reflected by a change in the μ parameter. Conversely, an effect in the tail of the RT distribution, as is seen in the overadditive and underadditive interactions between the effect of manipulation and quantiles in the quantile plot, is reflected in the τ parameter.

In sum, analysis of the RT distribution is more informative than the analysis of mean RT alone, as it can be used to draw a refined picture of how an experimental manipulation like semantic relatedness of prime and target impacts on the different part(s) of the RT distribution—effects that are missed when analysing only the mean RT. Capturing these effects on the RT distribution, either through visualising them in quantile and difference plots or summarising them in the ex-Gaussian parameters, has the potential to reveal the nature of the processes underlying the effect in question.

RT Distribution Analysis: The Semantic Priming Effect

In this thesis, RT distribution analysis will be used as a magnifying glass to investigate the processes that underlie the semantic priming effect at a short SOA in the lexical decision and semantic categorization tasks. From the widely held view that semantic priming effects at short SOAs are driven by an automatic spreading activation process, in which the prime pre-activates the target, providing it with a processing head-start, it would be predicted that automatic semantic priming effects are reflected as a distributional shift (e.g., Figure 1A and 1B). However, as was outlined in the previous sections, in the lexical decision task, semantic priming effects at short SOAs need not be automatic and could instead be driven by the retrospective semantic matching strategy. Support for this view was found by both Balota et al. (2008) and Gomez et al. (2013) by demonstrating that with unmasked primes at a short SOA (250 ms), semantic priming effects are reflected in an increase in the effect across the quantiles, with the magnitude of the semantic priming effect greater in the later quantiles (e.g., Figure 1C and 1D). Balota et al. (2008) suggested that this overadditive interaction reflects a retrospective prime retrieval process, with the prime exerting a larger effect on the decision to the target when more time is available, hence impacting on the size of the semantic priming effect mainly in the higher quantiles.

Direct evidence for this retrospective notion was found in Thomas, Neely, and O'Connor's (2012) lexical decision study, in which the direction of prime–target relatedness was manipulated to isolate the retrospective process from prospective processes like automatic spreading activation and expectancy generation. While prospective processes can produce semantic priming effects that have a forward association (e.g., *keg–BEER,* in which the prime would pre-activate the target), only retrospective processes can produce semantic priming effects for backward-associated prime–target pairs (e.g., *cut–CREW*; *small–SHRINK*, in which the target would pre-activate the prime, but the prime not the target). On the rationale that semantic priming effects obtained with backward-associated prime–target pairs reflect the use of the retrospective semantic matching strategy (e.g., Kahan, Neely, & Forsyth, 1999), Thomas et al. compared RT distribution patterns obtained with prime-target pairs that had either a forward association only (e.g., *keg–BEER*), a symmetrical association (e.g., *east–west*), or a backward-association only (e.g., *small–SHRINK)*. In line with the view that an increase in the size of the semantic priming effect in the tail of the RT distribution reflects the retrospective semantic matching strategy, Thomas et al. found that only the semantic priming effects that were obtained with backward-associated prime–target pairs (i.e., the symmetrical and backward-associated only pairs) were manifested as overadditive interactions.

RT distribution analysis has thus been shown to be a useful tool for revealing the underlying process of the semantic priming effect in the lexical decision task, with several studies demonstrating that the semantic priming effect obtained in the lexical decision task can be reflected in an overadditive interaction—the pattern that has been associated with the use of the retrospective semantic matching strategy. The RT distribution pattern of the semantic priming effect obtained in a semantic categorization task, in which retrospective use of the prime is assumed to be precluded, has however not been examined. To investigate the process responsible for the semantic priming effect in the semantic categorization task, and whether this process differs from that in the lexical decision task, the RT distribution patterns reflecting the semantic priming effects obtained in both these tasks will be analysed in this thesis.

Thesis Outline

The goal of this thesis is to explore the processes that underlie semantic priming effects with visible (unmasked) primes at a short SOA (240 ms). In doing so, I will focus on the widely held view that semantic priming effects at short SOAs are driven by an automatic spreading activation process. Specifically, I will use RT distribution analyses to investigate the automaticity notions that semantic priming is "uncontrollable or involuntary" and that semantic priming can "occur without conscious awareness". The literature reviewed in Chapter 1 outlined the following three questions. First, if the spread of semantic activation at a short SOA is automatic and therefore "uncontrollable", then could RP modulate the size of the semantic priming effect in a task that precludes the retrospective semantic matching strategy? This will be investigated in Chapter 2 by manipulating RP at a short SOA in a semantic categorization task. Second, if the process responsible for semantic priming effects in the lexical decision task is different to that in the semantic categorization task, then is the process responsible for the modulation of the size of the semantic priming effect (that is, the RP effect) also task-dependent? This will be investigated in Chapter 3 by manipulating RP at a short SOA in a lexical decision task and contrasting the RT distribution patterns of the obtained effects with those obtained in the semantic categorization task in Chapter 2. And third, if the spread of semantic activation can "occur without conscious awareness", then why are masked semantic priming effects so elusive? This will be investigated in Chapter 4 by manipulating prime visibility, using both masked and unmasked primes in a lexical decision and semantic categorization task, and contrasting the obtained RT distribution patterns. Finally, in Chapter 5, the findings from the mean RT and RT distribution analyses will be summarised and drawn together to create a more complete picture of the processes that underlie semantic priming effects at short SOAs and re-evaluate the notion that semantic priming effects at short SOAs reflect an automatic spreading activation process.

References

Antos, S. J. (1979). Processing facilitation in a lexical decision task. *Journal of Experimental Psychology, 5*, 527-545.

Balota, D. A., & Yap, M. J. (2011). Moving beyond the mean in studies of mental chronometry: The power of response time distributional analyses. *Current Directions in Psychological Science, 20*, 160-166.

Balota, D. A., Yap, M. J., Cortese, M. J., & Watson, J.M. (2008). Beyond mean response latency: Response time distributional analysis of semantic priming. *Journal of Memory and Language, 59*, 495-523.

Becker, C. A. (1980). Semantic context effects in visual word recognition: An analysis of semantic strategies. *Memory & Cognition, 8*, 493-512.

Bueno, S., & Frenck-Mestre, C. (2002). Rapid activation of the lexicon: A further investigation with behavioral and computational results. *Brain and Language, 81*, 120-130.

Bueno, S., & Frenck-Mestre, C. (2008). The activation of semantic memory: Effects of prime exposure, prime–target relationship, and task demands. *Memory & Cognition, 36*, 882-898.

Collins, A. M., & Loftus, E. F. (1975). A spreading-activation theory of semantic processing. *Psychological Review, 82*, 407-428.

Damian, M. F. (2001). Congruity effects evoked by subliminally presented primes: Automaticity rather than semantic processing. *Journal of Experimental Psychology: Human Perception and Performance, 27*, 154-165.

De Groot, A. M. B. (1984). Primed lexical decision: Combined effects of the proportion of related prime–target pairs and the stimulus-onset asynchrony of prime and target. *The Quarterly Journal of Experimental Psychology Section A, 36*, 253-280.

Dehaene, S., Naccache, L., Le Clec'H, G., Koechlin, E., Mueller, M., Dehaene-Lambertz, G., Van de Moortele, P. F., & Le Bihan, D. (1998). Imaging unconscious semantic priming. *Nature, 395*, 597-600.

Forster, K. I., & Davis, C. (1984). Repetition priming and frequency attenuation in lexical access. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 10*, 680-698.

Forster, K. I., Mohan, K., & Hector, J. (2003). The Mechanics of Masked Priming. In S. Kinoshita & S. Lupker (Eds.), *Masked Priming: The State of the Art* (pp. 3-37). New York: Psychology Press.

Frenck-Mestre, C., & Bueno, S. (1999). Semantic features and semantic categories: Differences in rapid activation of the lexicon. *Brain and Language, 68*, 199-204.

Fuentes, L. J., & Carmona, E., Agis, I. F., & Catena, A. (1994). The role of the anterior attention system in semantic processing of both foveal and parafoveal words. *Journal of Cognitive Neuroscience, 6*, 17-25.

Gomez, P., Perea, M., & Ratcliff, R. (2013). A diffusion model account of masked vs. unmasked priming: Are they qualitatively different? *Journal of Experimental Psychology: Human Perception and Performance*, *39,* 1731-1740.

Heathcote, A., Popiel, S. J., & Mewhort, D. J. K. (1991). Analysis of response time distributions: An example using the Stroop task. *Psychological Bulletin, 109*, 340-347.

Hohle, R. H. (1965). Inferred components of reaction times as functions of foreperiod duration. *Journal of Experimental Psychology, 69*, 382-386.

Holender, D. (1986). Semantic activation without conscious identification in dichotic listening, parafoveal vision, and visual masking: A survey and appraisal. *Behavioral and Brain Sciences, 9*, 1-23.

Hutchison, K. A. (2007). Attentional control and the relatedness proportion effect in semantic priming. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 33*, 645-662.

Hutchison, K. A., Neely, J. H., & Johnson, J. D. (2001). With great expectations, can two “wrongs” prime a “right”? *Journal of Experimental Psychology: Learning, Memory, and Cognition, 27*, 1451-1463.

Jiang, Y., Rouder, J. N., & Speckman, P. L. (2004). A note on the sampling properties of the Vincentizing (quantile averaging) procedure. *Journal of Mathematical Psychology*, *48*, 186-195.

Kahan, T. A., Neely, J. H., & Forsythe, W. (1999). Dissociated backward priming effects in lexical decision and pronunciation tasks. *Psychonomic Bulletin & Review, 6*, 105-110.

Kouider, S., & Dehaene, S. (2007). Levels of processing during non-conscious perception: A critical review of visual masking. *Philosophical Transactions of the Royal Society B: Biological Sciences, 362*, 857-875.

Kunde, W., Kiesel, A., & Hoffman, J. (2003). Conscious control over the content of unconscious cognition. *Cognition, 88*, 223-242.

Lupker, S. J. (1984). Semantic priming without association: A second look. *Journal of Verbal Learning and Verbal Behavior, 23*, 709-733.

Masson, M. E. J. (1995). A distributed memory model of semantic priming. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 21*, 3-23.

McNamara, T.P. (2005). *Semantic priming: Perspectives from memory and word recognition.* New York: Psychology Press.

McRae, K., & Boisvert, S. (1998). Automatic semantic similarity priming. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 24*, 558-572.

McRae, K., de Sa, V. R., & Seidenberg, M. S. (1997). On the nature and scope of featural representations of word meaning. *Journal of Experimental Psychology: General, 126*, 99-130.

Meyer, D. E., & Schvaneveldt, R. W. (1971). Facilitation in recognizing pairs of words: Evidence of a dependence between retrieval operations. *Journal of Experimental Psychology, 90*, 227-234.

Moors, A., & De Houwer, J. (2006). Automaticity: A theoretical and conceptual analysis. *Psychological Bulletin, 132*, 297-326.

Neely, J. H. (1976). Semantic priming and retrieval from lexical memory: Evidence for facilitatory and inhibitory processes. *Memory & Cognition, 4*, 648-654.

Neely, J. H. (1977). Semantic priming and retrieval from lexical memory: Roles of inhibitionless spreading activation and limited-capacity attention. *Journal of Experimental Psychology: General, 106*, 226-254.

Neely, J. H. (1991). Semantic priming effects in visual word recognition: A selective review of current findings and theories. In D. Besner & G.W. Humphreys (Eds.), *Basic processes in reading: Visual word recognition* (pp. 264-336). Hillsdale, NJ: Erlbaum.

Neely, J. H., & Kahan, T. A. (2001). Is semantic activation automatic? A critical re-evaluation. In H.L. Roediger, III, J.S. Nairne, I. Neath, & A.M. Suprenant (Eds.), *The nature of remembering: Essays in honor of Robert G. Crowder* (pp. 69-93). Washington, DC: American Psychological Association.

Neely, J. H., & Keefe, D. E. (1989). Semantic context effects on visual word processing: A hybrid prospective/retrospective processing theory. In G.H. Bower, (Ed.), *The psychology of learning and motivation: Advances in research and theory,* Vol. 24 (pp. 207-248). New York: Academic Press.

Neely, J. H., Keefe, D. E., & Ross, K. L. (1989). Semantic priming in the lexical decision task: Roles of prospective prime-generated expectancies and retrospective semantic matching. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 15*, 1003-1019.

Norris, D. (1984). The mispriming effect: Evidence for an orthographic check in the lexical decision task. *Memory & Cognition, 12*, 470-476.

Plaut, D. C., & Booth, J. R. (2000). Individual and developmental differences in semantic priming: Empirical and computational support for a single-mechanism account of lexical processing. *Psychological Review, 107*, 786-823.

Posner, M. I., & Snyder, C. R. R. (1975). Attention and cognitive control. In R.L. Solso (Ed.), *Information processing and cognition: The Loyala symposium* (pp. 55-85). Hillsdale, NJ: Lawrence Erlbaum Associates, Inc.

Pratte, M. S., Rouder, J. N., Morey, R. D., & Feng, C. (2010). Exploring the differences in distributional properties between Stroop and Simon effects using delta plots. *Attention, Perception & Psychophysics, 72*, 2013-2025.

Quinn, W. M., & Kinoshita, S. (2008). Congruence effect in semantic categorization with masked primes with narrow and broad categories. *Journal of Memory and Language, 58*, 286-306.

Reynvoet, B., Gevers, W., Caessens, B. (2005). Unconscious primes activate motor codes through semantics. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 31*, 991-1000.

Ratcliff, R. (1979). Group reaction time distributions and an analysis of distribution statistics. *Psychological Bulletin, 86*, 446-461.

Ratcliff, R. (2012). Response time distributions. In H. Cooper, P.M. Camic, D.L. Long, A.T. Panter, D. Rindskopf, & K.J. Sher (Eds.), APA handbook of research methods in psychology, Vol 1: Foundations, planning, measures, and psychometrics (pp. 429-443). Washington, DC, US: American Psychological Association, xliv, 744 pp.

Shelton, J. R., & Martin, R. C. (1992). How semantic is automatic semantic priming? *Journal of Experimental Psychology: Learning, Memory, and Cognition, 18*, 1191-1210.

Smith, E. E., Shoben, E. J., & Rips, L. J. (1974). Structure and process in semantic memory: A featural model for semantic decisions. *Psychological Review, 81*, 214-241.

Spieler, D. H., Balota, D. A., & Faust, M. E. (2000). Levels of selective attention revealed through analyses of response time distributions. *Journal of Experimental Psychology: Human Perception and Performance, 26*, 506-526.

Stolz, J. A., & Besner, D. (1999). On the myth of automatic semantic activation in reading. *Current Directions in Psychological Science, 8*, 61-65.

Thomas, M. A., Neely, J. H. & O'Connor, P. (2012). When word identification gets tough, retrospective processing comes to the rescue. *Journal of Memory and Language, 66*, 623-643.

Tweedy, J., Lapinski, R., & Schvaneveldt, R. (1977). Semantic-context effects on word recognition: Influence of varying the proportion of items presented in an appropriate context. *Memory & Cognition, 5*, 84-89.

Van den Bussche, E., Van den Noortgate, W., & Reynvoet, B. (2009). Mechanisms of masked priming: A meta-analysis. *Psychological Bulletin, 135*, 452-477.

Chapter 2—Relatedness Proportion Effects in Semantic Categorization: Reconsidering the Automatic Spreading Activation Process

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Relatedness Proportion Effects in Semantic Categorization: Reconsidering the Automatic Spreading Activation Process

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Abstract

Semantic priming effects at a short prime–target stimulus onset asynchrony are commonly explained in terms of an automatic spreading activation process. According to this view, the proportion of related trials should have no impact on the size of the semantic priming effect. Using a semantic categorization task ("Is this a living thing?"), we show that on the contrary there is a robust effect of relatedness proportion on the size of semantic priming effect. This effect is not due to the participants using the prime to predict the target category/response, as manipulating the proportion of category/response-congruent trials produces a very different pattern. Taken together with response time (RT) distribution analysis we argue that the semantic priming effect observed here is best explained in terms of an evidence accumulation process and source confusion between the prime and target.

Keywords: Semantic priming; automatic spreading activation; evidence accumulation; source confusion and prime discounting

Introduction

The semantic priming effect is one of the most robust phenomena in word recognition and refers to the finding that words are responded to faster when they are preceded by a semantically related word (e.g., *dog*–*CAT*) compared to an unrelated word (e.g., *bread*–*CAT*; Meyer & Schvaneveldt, 1971; for reviews see McNamara, 2005; Neely 1991).

Almost all accounts of semantic priming appeal to the notion of spreading activation (Posner & Snyder, 1975). In localist models, concepts are represented as interconnected nodes in a network (e.g., Collins & Loftus, 1975): When a node is activated, activation spreads across links to other, related nodes, with activation getting weaker across distance and with time. *CAT* would therefore receive greater activation from a related prime *dog* than from an unrelated prime *bread*, because the former is closer to the target within the semantic network. Distributed models (e.g., Masson, 1995; McRae, de Sa, & Seidenberg, 1997; Plaut & Booth, 2000; Smith, Shoben & Rips, 1974) assume that concepts are specified by a set of semantic features (e.g., <has fur>, <has a tail>, <meows>) and that access to a particular concept is represented by an activation pattern across the feature set. Presenting a semantically related prime activates a similar set of semantic features, thus helping the activation pattern for the target to settle faster.

In the present study, we test the automaticity of semantic priming effects by manipulating the proportion of related trials, at a short (240 ms) prime–target stimulus onset asynchrony (SOA), using a semantic categorization ("Is this a living thing?") task. In addition to the automatic spreading activation process, semantic priming effects can be produced by a conscious prediction strategy, in which limited-capacity attention is used to generate an expectancy regarding the upcoming target's identity from the prime. It is widely assumed that it takes time (generally more than 400 ms) to generate expectancies (Neely, 1977; see Hutchison, 2007 for a review), so at the SOA of 240 ms, only the automatic spreading activation process should be at play. If semantic priming effects reflect activation that spreads *automatically* from the prime to the target, then the proportion of related trials in an experiment should have no impact on the size of the semantic priming effect. To anticipate the results, we found a robust effect of relatedness proportion (RP), in contradiction to the automatic spreading activation account. In Experiment 2, we tested and ruled out the possibility that the semantic priming effects were due to response priming (i.e., the prime is used to predict the response to the target). In this experiment, the proportion manipulation concerned category- (and hence response-) congruent primes that were not semantically related to the target (e.g., *seal–EAGLE, rifle–COUCH*). The congruency proportion manipulation produced a very different pattern of data from the manipulation of RP. These data are taken to argue against the automatic spreading activation account of semantic priming in semantic categorization. In the second part of the article, we present an analysis of RT distribution to make a case for an alternative account that explains semantic priming effects in semantic categorization in terms of evidence accumulation and source confusion.

An important departure from previous studies is that we used a semantic categorization task, instead of the lexical decision task, the task most frequently used to investigate semantic priming. We first present a brief review of the literature to explain why we chose this task.

RP Effects in Lexical Decision and Post-Lexical Coherence Checking

Tweedy, Lapinski, and Schvaneveldt (1977) were the first to manipulate RP, the proportion of related trials (e.g., *dog–CAT*) in an experimental list. They reported that the size of the semantic priming effect increased when RP was high compared to when it was low. They called this the *relatedness proportion effect* (RP effect) and took the effect as a marker of strategic processing. In this strategy, participants generate expectancies about the upcoming target from the prime adaptively, that is, when such a strategy is successful on a high proportion of trials (in the high RP condition) but not when it leads to wrong predictions on a high proportion of trials (in the low RP condition). In contrast, in the automatic spreading activation process, activation spreads automatically from the prime, regardless of RP. On the assumption that generating expectancies takes time, RP effects should be present at long prime–target SOAs but absent at short SOAs, where semantic priming effects are due to automatic spreading activation.

Hutchison (2007) reviewed lexical decision and word naming (pronunciation) studies manipulating both RP and prime–target SOA and concluded that findings were generally consistent with the above prediction: RP manipulation increases semantic priming effects "only when the SOA is long enough for participants to consciously generate likely targets" (p. 646). Across 24 experiments, reliable positive RP effects were only found with prime–target SOAs of 240 ms or longer. The absence of RP effects at short SOAs is widely regarded as evidence that semantic priming at short SOAs is produced by an automatic spreading activation process.

However, this conclusion is challenged by De Groot's (1984) study. She crossed the SOA manipulation (240 ms, 540 ms, and 1,040 ms) with the RP manipulation (.25, .50, .75, as well as 1.00 related trials) and found significant RP effects at all three SOAs: The size of the semantic priming effect increased from the low (.25) to the high (.75) RP proportion conditions by 16, 25, and 64 ms respectively. The significant RP effect at the short (240 ms) SOA is at odds with the assumption that semantic priming effects obtained at a short SOA are automatic. Instead, De Groot explained the result in terms of a post-lexical coherence checking strategy (what Neely, 1991, referred to as the *retrospective semantic matching strategy*).

In this strategy, the meaning of the target is compared to that of the prime before a lexical decision to the target is made, and the semantic relatedness between the prime and target contributes towards the lexical decision. If the prime and target are found to be related, the decision is biased toward a "word" decision, whereas the absence of a semantic relationship between the prime and target generates a bias toward responding "nonword". The bias toward responding "nonword" created by the absence of a semantic relationship is revealed by a *nonword facilitation effect*, a faster response to nonword targets preceded by an unrelated word prime (e.g., *doctor–SLINT*) relative to an informationally neutral prime (e.g., *XXXX–SLINT*). The same bias also delays the response to word targets that are preceded by a semantically unrelated prime (e.g., *doctor–BUTTER*), resulting in inhibition effects and hence increasing the net semantic priming effect. The post-lexical coherence checking strategy operates even at the short prime–target SOA, because it is retrospective—it does not operate until the target is presented.

Neely, Keefe and Ross (1989) have pointed out that the RP manipulation is typically confounded with the proportion of nonwords given an unrelated word prime—what they referred to as the *nonword ratio*—and De Groot's (1984) study was no exception. In De Groot's low RP condition, the nonword ratio was relatively high: Of the targets paired with an unrelated word prime, 80 were nonword targets and 60 were word targets, hence a bias toward responding "nonword" when there is no semantic relationship between the prime and target would be viable. When Neely et al. (1989) manipulated RP and nonword ratio independently in their own study, they found that the nonword ratio affected the size of the semantic priming effect, even when RP was held constant. Neely et al. concluded that the RP effects observed in lexical decision tasks reflect the influence of both RP and nonword ratio, with the RP manipulation mainly driving the generation of expectancy and nonword ratio the use of post-lexical coherence checking.

Semantic Categorization

De Groot's (1984) study showed that using a short SOA does not warrant that the semantic priming effect reflects only the automatic spreading activation process in a lexical decision task, because the post-lexical coherence strategy can operate at a short SOA.[1] Excluding the use of this post-lexical strategy from the lexical decision task has proven to be difficult, given that the presence of a semantic relationship between the prime and target is a strong cue to the target's lexical status.[2] As pointed out by Neely et al. (1989), in the lexical decision task, RP is almost always confounded with the nonword ratio, and separating the two requires a very large number of filler trials.

In a semantic categorization task, participants are required to decide whether the target belongs to a semantic category (e.g., "living thing"). In this task, manipulation of RP can be readily unconfounded from the nonword ratio, because the task does not require nonwords. Decision bias can easily be avoided in the semantic categorization task by equating RP for exemplar and non-exemplar targets (McRae, et al., 1997), which can be done without using a large number of filler trials, unlike in the lexical decision task. When semantic categorization and a short SOA are used, both the post-lexical coherence checking and expectancy generation strategies can be precluded, making the RP manipulation a clean way to test the automaticity of semantic priming effects.

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[1] We note that Neely and Keefe (1989) suggested on the contrary that the post-lexical coherence checking process does not operate at short SOAs because participants fail to reach the prime's meaning before the target appears. This claim seems to have been motivated by their failure to find a nonword facilitation effect at a short SOA, which is contradicted by De Groot's (1984) finding.

[2] Except when the nonwords resemble specific words and are paired with "semantically related" word primes, e.g., *apple–FROIT; father–MOHTER*. With the exception of few studies (e.g., Antos, 1979; Norris, 1984; O'Connor & Forster, 1981) most semantic priming studies have not used "semantically related" primes with the nonword targets.

Experiment 1

We tested the automaticity of semantic priming effects in a semantic categorization task. By using a short prime–target SOA in a task that does not require word–nonword discrimination, we ensured that both the expectancy generation and post-lexical coherence checking strategies were precluded, allowing the RP manipulation (.25 vs. .75 related) to directly test the automaticity of semantic priming. According to the automatic spreading activation account, semantically related primes should pre-activate the semantic features of the related target automatically, regardless of RP, and hence semantic priming effects should be present and constant across the different RP levels.

Method

Participants. Sixty-four undergraduate students of Macquarie University in Sydney, 49 women and 15 men (M_{age} = 22.5 years) enrolled in cognitive psychology courses, participated in Experiment 1 in return for course credit. All participants had normal or corrected-to-normal vision. Of those, data from four participants were excluded because of a high (over 15%) error rate.

Design. The experiment used a 2 (RP: low [.25 related] vs. high [.75 related]) x 2 (prime relatedness: semantically related vs. semantically unrelated) factorial design, with RP manipulated between groups and prime relatedness within subjects. The dependent variables were RT and error rate.

Stimuli. A semantic categorization ("Animals") task was used. The critical target items consisted of 40 animal exemplars (mammal, birds, marine animals, birds, insects) and 40 nonanimal exemplars of manmade items (musical instruments, household items, vehicles, tools, etc.). The Animal exemplar targets were on average 6.6 letters long (range 3–10) and had an average Log Subtitle Contextual Diversity value (LgSUBTLCD) of 1.95 (LgSUBTLCD is the Log of the SUBTLEX contextual diversity value, corresponding to the percentages of films containing the word, and is argued by Brysbaert & New (2009) to be the best predictor of lexical decision latency. It is highly correlated with Log word frequency). The nonanimal targets were on average 6.4 letters long (range 3–10) and had an average LgSUBTLCD of 2.35.

Each target was paired with two primes; a semantically related prime (e.g., *hawk–EAGLE; sofa–COUCH*) and a semantically unrelated, category-incongruent prime (e.g., *chain–EAGLE; squid–COUCH*). The related primes were selected on the basis of high semantic similarity according to the McRae, Cree, Seidenberg, and McNorgan's (2005) semantic feature production norms. These norms include 541 concepts (of living- and nonliving things), with 2,526 features, and similarity between two concepts is represented by the cosine, "the dot product between two concept vectors, divided by the product of their lengths" (p.553). Cosine ranges from -1 (opposite vectors) to 1 (identical vectors), with 0 indicating independent vectors. On the basis of these cosines, the average similarity for the animal targets was .64 and for the nonanimal targets was .62. Primes never occurred as targets. The critical targets were divided into two sets, matched on mean length, frequency, and similarity. The assignment of lists to the prime conditions was counterbalanced so that each prime and target occurred once as a related pair and once as an unrelated pair across the two lists. The stimuli are listed in the Appendix.

To manipulate RP, we used 80 filler trials, of which half were animal and half were nonanimal targets. The animal filler targets had an average length of 6.6 letters and LgSUBTLCD of 1.83; the nonanimal targets an average length of 6.3 letters and LgSUBTLCD of 2.4. By re-pairing the primes and targets of these filler trials so that either all or none of the filler trials were semantically related, lists with RPs of .25 (low RP) and .75 (high RP) were created. Because not all animal words appeared in the

McRae et al. (2005) norms, the average relatedness for the filler items was verified using the Latent Semantic Analysis norms (LSA, Landauer, McNamara, Dennis, & Kintsch, 2007) According to LSA the average relatedness of the filler trials was .04 for the low RP condition and .32 for the high RP condition.

The word pairs in the practice phase were comparable to the critical target items used in the test phase. There were 16 practice trials, eight of each category, in which RP was kept equal to that of the test list. The first two trials of each block were warm-up trials. Neither the practice nor the warm-up trials were included in the analysis.

Apparatus and procedure. Participants were tested in groups of one to four. The Windows-based DMDX display system (version 3.1) developed by Forster and Forster (2003) was used for stimulus presentation and data collection. The stimuli were presented on a 19-inch CRT monitor, situated approximately 50 cm from the participant. Stimulus display was synchronized to the screen refresh rate (13.3 ms). Responses were collected with an external response pad with three response keys, of which the two end keys were marked as **+** and **–**.

Each participant completed 160 trials, preceded by 16 practice and two warm-up trials. A self-paced break was included after the first 80 trials. Each trial had the following sequence: a fixation sign (+) presented for 253 ms, followed by a prime in lowercase letters presented for 200 ms, a 40 ms blank and the uppercase target. The target remained on the screen until the participant's response or for 2,000 ms whichever occurred sooner. Feedback was given only on trials on which participants made an error. Each response was followed by an intertrial interval of 971 ms. If the response was incorrect, the word *wrong* was displayed for 466 ms during the intertrial interval.

At the outset of the experiment, participants were informed that they had to categorize the uppercase word as an animal or a nonanimal as quickly and accurately as possible. It was explained that "animal" referred to living things in general, including mammals, reptiles, fish, and birds. No mention was made of the relatedness of the prime and target. Participants were instructed to keep their index fingers on the two end buttons of the response pad. Participants pressed the + button for animal targets and the – button for nonanimal targets.

Participants received different random order of trials. Prime and target were presented in the center of the screen in white letters on a black background, using 11-point Courier font. Feedback was also presented in white, just below of the center of the screen.

Results

In both Experiments 1 and 2 the preliminary treatment of data was as follows. Error trials were excluded from the RT analysis. To reduce the effect of extremely short and long RTs, RTs greater than or equal to 3 standard deviations from the participant's individual mean RT were replaced by the relevant cut-off value. This affected, on average, 1.75% of the trials in Experiment 1. A two-way analysis of variance (ANOVA) was used with the factors prime relatedness (semantically related vs. unrelated) and RP (.25 vs. .75 related). In the by-subjects analysis (F_1), prime relatedness was a within-subject factor and RP was a between-subjects factor; in the by-items analysis (F_2), both were within-item factors. An alpha level of .05 was used. The mean RTs, standard errors and error rates for Experiment 1 are presented in Table 1.

RT. The main effect of prime relatedness was significant ($F_1(1,58) = 48.61$, $p < .001$, $\eta^2 = .456$; $F_2(1,79) = 69.53$, $p < .001$, $\eta^2 = .468$), with faster RTs in the semantically related than in the category-incongruent condition, demonstrating semantic priming. The main effect of RP did not reach significance in the by-subjects analysis ($F_1(1,58) = 2.61$, $p = .112$, $\eta^2 = .043$, but $F_2(1,79) = 50.20$, $p < .001$, $\eta^2 = .389$), Critically, RP interacted with prime relatedness (F_1(1,58) = 23.44, p < .001, η^2 = .288; F_2(1,79) = 53.35, p < .001, η^2 = .403), demonstrating an RP effect. Planned contrasts revealed that there was a large semantic priming effect in the high RP condition (F_1(1,29) = 59.34, p < .001, η^2 = .672; F_2(1,79) = 142.00, p < .001, η^2 = .643), whereas in the low RP condition the semantic priming effect did not reach significance (F_1(1,29) = 2.76, p = .108, η^2 = .087; F_2(1,79) = 3.54, p = .064, η^2 = .043).

Error rate. The main effect of prime relatedness was significant (F_1(1,58) = 15.23, p < .001, η^2 = .208; F_2(1,79) = 22.31, p < .001, η^2 = .220), with fewer errors in the semantically related than in the category-incongruent condition. The RP effect was also significant, as revealed by the prime relatedness by RP interaction (F_1(1,58) = 13.00, p = .001, η^2 = .183; F_2(1,79) = 20.90, p < .001, η^2 = .209). Similar to the RT data, a significant semantic priming effect was found in the high RP condition (F_1(1,29) = 22.20, p < .001, η^2 = .434; F_2(1,79) = 32.92, p < .001, η^2 = .294), but not in the low RP condition (F_1(1,29) = 0.06, p = .808, η^2 = .002; F_2(1,79) = 0.10, p = .758, η^2 = .001).

Table 1

Mean response latencies (in Milliseconds), Standard Errors and Percentage Error Rates (%E) in Experiment 1

	Prime relatedness							
	Semantically related			Semantically unrelated			Priming effect	
Relatedness proportion	RT	*SE*	%E	RT	*SE*	%E	In ms	%E
25%	594	14.27	4.9	605	16.02	5.2	11	0.3
75%	541	11.39	3.0	599	10.83	9.3	58**	6.3**

Note. RT = response time.
** p < .001.

Discussion

The main finding of Experiment 1 is that a robust RP effect was obtained at a short (240 ms) prime–target SOA, a level widely regarded in the literature as too short for expectancies to be generated. An RP effect at a short SOA was also reported by De Groot (1984), using a lexical decision task. De Groot explained her result in terms of the post-lexical coherence checking strategy, in which an absence of a semantic relationship between the prime and the target creates a bias toward responding "nonword". Neely et al. (1989) showed that the factor responsible for the post-lexical coherence checking strategy (or, in their terms, the retrospective semantic matching strategy) is the nonword ratio, which is typically confounded with RP. In our semantic categorization task, there were no nonwords, and RP was equated for the "animal" and "nonanimal" responses, precluding a decision bias based on prime–target relatedness. In sum, the present RP effect cannot be explained either in terms of either expectancy generation or a post-lexical coherence check, and thus challenges the view that semantic priming effects at a short prime–target SOA reflect an automatic spreading activation process.

Experiment 2

Although our semantic categorization task precluded a decision bias based on the post-lexical coherence checking strategy, it is possible that a different type of decision/response bias may have been responsible for the RP effect found in Experiment 1. In lexical decision, both semantically related and semantically unrelated primes belong to the "word" category. In contrast, in our semantic categorization experiment, semantic relatedness was confounded with category congruence and hence response congruence. Accordingly, the semantic priming effect observed here may be attributed to category/response cuing: That is, participants may have used the prime category (e.g., "animal" for the prime *hawk*; "nonanimal" for the prime *sofa*) to predict the category/response to the target (e.g., "animal" for *EAGLE*; "nonanimal" for *COUCH*). In the high RP condition, the prime category/response would be a valid indicator of the target category/response on 75% of the trials. Thus, the RP effect observed in Experiment 1 may have reflected a greater tendency to make use of the prime category/response to predict the target category/response in the high RP condition.

We believe the category/response cuing is unlikely to explain the pattern of the RP effect in Experiment 1, however. Consider the low RP condition. Here, 25% of the trials were category-congruent, and 75% of the trials were category-incongruent. This means that on 75% of the trials, the target category/response was the opposite of the prime category/response. In other words, the prime category was an equally valid indicator of the target category/response in the low RP condition, and hence response cuing would be just as effective in the low RP condition as in the high RP condition, except that the opposite category/response is cued. This should result in an advantage for the category-incongruent trials, that is, a *reversed* priming effect, not a reduced (but positive) priming effect as was observed in the low RP condition in Experiment 1. Consistent with this, using a semantic categorization task with number words ("Is the number odd or even?"), Kinoshita, Mozer and Forster (2011, Experiment 1) observed a reversed priming effect in a low RP condition (in which 20% of the trials were category-congruent, e.g., *two–FOUR*, and 80% of the trials were category-incongruent, e.g., *one–FOUR*).

In Experiment 2, we tested the response-cuing account. In this experiment, the semantically related prime–target pairs (e.g., *hawk–EAGLE, sofa–COUCH*) used in Experiment 1 were changed so that they were now category-congruent but otherwise semantically unrelated: e.g., *seal–EAGLE; rifle–COUCH* (The unrelated prime–target pairs were unchanged, and remained semantically unrelated and category-incongruent, e.g., *chain–EAGLE; squid–COUCH*). Hence in Experiment 2, what was manipulated was the proportion of category-congruent trials: In the high RP condition 75% of the trials were category-congruent and 25% were category-incongruent, and in the low RP condition, 25% of the trials category-congruent and 75% were category-incongruent. On the one hand, if the semantic priming effect in Experiment 1 was simply a category/response cuing effect, we expect to find an identical pattern of proportion effects in Experiment 2. On the other hand, finding a different pattern of results in Experiments 1 and 2 would indicate that the semantic priming effect in Experiment 1 cannot be explained simply as a response cuing effect.

Method

Participants. Fifty-nine undergraduate students of Macquarie University in Sydney, 41 women and 18 men (M_{age} = 21.5 years) enrolled in cognitive psychology courses, participated in Experiment 2 in return for course credit. All participants had normal or corrected-to-normal vision. Three participants were excluded from the analysis because of high error rates (higher than 20%).

Design, stimuli, apparatus, and procedure. The design, apparatus, and procedure were the same as those in Experiment 1. The only difference from Experiment 1 was the change to the "related" prime–target pairs. They were re-paired so that the prime was category-congruent with the target, but semantically unrelated (*e.g., seal–EAGLE; rifle–COUCH*). The unrelated prime–target pairs were unchanged from Experiment 1, and were semantically unrelated and category-incongruent *(e.g., chain–EAGLE; squid–COUCH).* For the critical category-congruent trials, the cosines representing semantic relatedness for the animal targets were .07 according to the McRae et al. (2005) norms and .14 according to the LSA norms, and for the nonanimal targets, the cosine values were .01 according to the McRae norms and .08 according to the LSA norms. LSA norms showed a similarity of .08 in the high RP condition and .04 in the low RP condition. The critical prime–target pairs are listed in the Appendix.

Results

The preliminary treatment of outliers in the RT data affected on average 1.68% of the trials. The mean RTs, standard errors and error rates for Experiment 2 are presented in Table 2.

For RT, neither the main effect of category congruence ($F_1(1,54) = 0.15$, $p = .702$, $\eta^2 = .003$; $F_2(1,79) = 0.05$, $p = .833$, $\eta^2 = .001$) nor the main effect of RP ($F_1(1,54) = 0.21$, $p = .647$, $\eta^2 = .004$; $F_2(1,79) = 3.80$, $p = .055$, $\eta^2 = .046$) was significant. Critically, category congruence and RP interacted ($F_1(1,54) = 12.07$, $p = .001$, $\eta^2 = .183$; $F_2(1,79) = 9.67$, $p = .003$, $\eta^2 = .109$), indicating that the size of the congruence effect differed between RP conditions. Planned comparisons revealed that in the high RP condition the congruence effect was non-significant ($F_1(1,27) = 3.21$, $p = .084$, $\eta^2 = .106$; $F_2(1,79) = 3.10$, $p = .082$, $\eta^2 = .038$), and in the low proportion condition, there was a reversed congruence effect showing an advantage for the category-incongruent targets ($F_1(1,27) = 14.47$, $p = .001$, $\eta^2 = .349$; $F_2(1,79) = 6.14$, $p = .015$, $\eta^2 = .072$).

For error rate, in line with the RT results, neither of the main effects was significant ($F_1(1,54) = 0.16$, $p = .693$, $\eta^2 = .003$; $F_2(1,79) = 0.21$, $p = .652$, $\eta^2 = .003$ and $F_1(1,54) = 2.31$, $p = .134$, $\eta^2 = .041$, but $F_2(1,79) = 5.74$, $p = .019$, $\eta^2 = .068$ for category congruence and RP, respectively). The category congruence by RP interaction was significant ($F_1(1,54) = 4.87$, $p = .032$, $\eta^2 = .083$; $F_2(1,79) = 5.16$, $p = .026$, $\eta^2 = .061$). As for the RT data, the interaction indicated that the direction of the category congruence effect is reversed in the two RP conditions. Separate analyses of the RP conditions showed that the category congruence effect was non-significant in the high proportion condition ($F_1(1,27) = 1.46$, $p = .237$, $\eta^2 = .051$; $F_2(1,79) = 1.88$, $p = .174$, $\eta^2 = .023$), and the reversed congruence effect in the low proportion condition was significant in the by-items analysis ($F_1(1,27) = 3.86$, $p = .060$, $\eta^2 = .125$, $F_2(1,79) = 4.02$, $p = .048$, $\eta^2 = .048$).

Table 2

Mean response latencies (in Milliseconds), Standard Errors, and Percentage Error Rates (%E) in Experiment 2

	Category congruence							
	Category congruent			Category incongruent			Priming effect	
Relatedness proportion	RT	*SE*	%E	RT	*SE*	%E	In ms	%E
25%	627	11.89	7.2	611	11.76	5.2	-16*	-2.0
75%	620	11.95	3.8	633	12.84	5.3	13	1.5

Note. RT = response time.
* $p < .05$.

Comparison of Experiment 1 and Experiment 2. To examine whether the semantic priming effect and the category congruence effect are the same, we combined the two experiments and analysed them using a three-way ANOVA with prime relatedness (related vs. unrelated), RP (low vs. high) and experiment (Experiment 1 vs. 2) as factors. For the by-subjects analysis the prime relatedness factor was a within-subject factor, and RP and Experiment were between-groups factors; for the by-items analysis, all three were within-item factors. We report the interactions involving the experiment factor that indicate that the semantic priming and category congruence manipulations are different.

For RT, the prime relatedness by experiment interaction was significant ($F_1(1,112) = 30.23$, $p < .001$, $\eta^2 = .213$; $F_2(1,79) = 35.78$, $p < .001$, $\eta^2 = .312$). This interaction indicated that the semantic priming effect was greater than the category congruence effect. The three-way (prime relatedness x RP x experiment) interaction was non-significant ($F_1(1,112) = 1.94$, $p = .167$, $\eta^2 = .017$; $F_2(1,79) = 3.57$, $p = .062$, $\eta^2 = .043$), indicating that the size of RP effects in Experiments 1 and 2 did not differ. However, separate analyses of the high and low RP conditions both showed a highly significant experiment x prime relatedness interactions: In the high RP condition, ($F_1(1,56) = 18.30$, $p < .001$, $\eta^2 = .246$; $F_2(1,79) = 30.23$, $p < .001$, $\eta^2 = .277$); in the low RP condition, ($F_1(1,56) = 12.00$, $p = .001$, $\eta^2 = .176$; $F_2(1,79) = 11.58$, $p = .001$, $\eta^2 = .128$). These interactions indicated that the semantic priming effect and the category congruence effect behaved differently in both the high- and low RP conditions.

For error rate, the prime relatedness by Experiment interaction was significant ($F_1(1,112) = 9.67$, $p = .002$, $\eta^2 = .079$; $F_2(1, 79) = 13.94$, $p < .001$, $\eta^2 = .150$), consistent with the RT data. The Experiment x prime relatedness interaction was significant in the high RP condition, ($F_1(1, 56) = 7.43$, $p = .009$, $\eta^2 = .117$; $F_2(1, 79) = 12.68$, $p = .001$, $\eta^2 = .138$), indicating that the semantic priming effect was greater than the category congruence effect, consistent with the RT data. None of the other main or interaction effects with the Experiment factor reached significance (all *F*s < 3.7, *p*s > .05).

Discussion

Experiment 2 used category congruent but semantically unrelated prime–target pairs (e.g., *seal–EAGLE* vs. *chain–EAGLE*), and manipulated the congruency proportion (75% category-congruent vs. 25% category-congruent). Congruency proportion modulated the size of the category congruence effect, but the pattern was quite different from that of Experiment 1. In Experiment 2, in the high RP condition a small and positive congruence-effect (13 ms) was found, and in the low RP condition the direction of the congruence effect was reversed (i.e., a congruence disadvantage was found, -16 ms).

As noted in the introduction to Experiment 2, this pattern of results is what is expected from response cuing. In the high RP condition, a target followed a prime that required the same response in 75% of the trials. In the low RP condition, the target followed a prime that required the *opposite* response in 75% of the trials. In other words, in both the high- and low-RP conditions, the prime category is a valid indicator of the target category/response in a large majority of trials. Thus, in the low-congruence proportion condition, the opposite response to the prime is cued, resulting in a reverse congruence effect (i.e., a congruency disadvantage), just as was observed in an odd–even decision task with number word stimuli by Kinoshita, et al. (2011, Experiment 1).

The pattern of RP effect observed here contrasted with the pattern found in Experiment 1. In Experiment 1 a large positive semantic priming effect (58 ms) was observed in the high RP condition and a weak and statistically non-significant, but positive priming effect (11 ms) was found in the low RP condition. The interactions involving the Experiment factor indicate the effects of category congruency proportion manipulation are quite different from the effects of RP manipulation. This dissociation indicates that the semantic priming effect produced by primes with semantic features overlapping with the target (e.g., *hawk–EAGLE; sofa–COUCH*) is not simply due to category congruence, and that the RP effect cannot be explained in terms of category/response cuing. The results of Experiment 1 are also incompatible with the automatic spreading activation process. How, then, can these effects be explained? This is the question we turn to next.

Semantic Priming as Evidence Accumulation and Source Confusion

As noted in the Introduction, almost all accounts of semantic priming effects appeal to the notion of spreading activation. Within the assumption that this occurs automatically—either within a localist semantic network, or via distributed semantic features—RP should have no impact on the size of semantic priming effects. In direct contradiction to this assumption, we observed a robust RP effect: The size of semantic priming effect was magnified fivefold in the high proportion (.75) condition relative to the low proportion (.25) condition.

We propose an alternative account of semantic priming effects in terms of evidence accumulation and source confusion. These notions are borrowed from the Bayesian Reader account of masked priming (Norris & Kinoshita, 2008) and the ROUSE (Responding Optimally with Unknown Source of Evidence; Huber, Shiffrin, Lyle, & Ruys, 2001) model of short-term priming. In the Bayesian Reader account, all decisions require task-specific computations: task performance is driven primarily by the nature of representations and decisions required by the task. The task dictates the hypothesis for which evidence is to be accumulated, for example, "the target is a word" in a lexical decision task or "the target is an animal" in semantic categorization. It is the decision required by the task that thus drives the priming effect, not simply the relationship between prime and target. As shown by Norris and Kinoshita (2008) in a series of masked priming experiments, the same prime and target pairs can result in different patterns of priming effects in different tasks.

The notion of *source confusion* plays a central role in Huber et al.'s (2001) ROUSE model to explain short-term priming (where the target immediately follows the prime without an intervening item between them). In short-term priming, where the prime and target are presented in close temporal and spatial proximity, the same evidence accumulation process is applied to the prime as the target, that is, the source of evidence is confused. To the extent that the evidence contributed by the prime is congruent with that required for the decision to the target, the decision to the target is facilitated, that is, priming is observed. Source confusion is counteracted by a mechanism called *discounting*, which "throws away" the evidence that is believed to have come from the wrong source, that is, from the prime and not the target. Prime features (e.g., <flies> <is a bird of prey> <lays eggs>) are by design shared by the target in a related trial (e.g., *hawk–EAGLE*) but not in an unrelated trial (e.g., *chain–EAGLE*). Thus discounting (throwing away) the prime features results in a reduction in the priming effect.

Weidemann, Huber, and Shiffrin (2008) proposed that the "prime diagnosticity"—defined as the relative proportion of trials in which the prime can be used to infer the correct answer—modulates the amount of evidence discounting. In the present RP manipulation, participants should discount the prime evidence when it is incongruent with the decision required to the target most of the time, that is, when the proportion of related trials is low. The net priming effect reflects a balance of source confusion and evidence discounting. A positive priming effect is observed if the amount of evidence accumulated from the prime is greater than the amount discounted; negative priming is observed if the amount of evidence discounted exceeds the amount accumulated from the prime. The RP effect observed in Experiment 1 is therefore readily accommodated by the evidence discounting notion.

What Constitutes the Evidence in Semantic Categorization?

According to the account we presented above, the semantic priming effect in semantic categorization reflects the evidence contributed by the prime toward a task-dependent hypothesis, and the RP effect is explained in terms of evidence discounting. But what constitutes the evidence? Although the notion of discounting was borrowed from, and is central to Huber et al.'s (2001) ROUSE model, the model does not specify a priori what constitutes the evidence. According to Norris and Kinoshita's (2008) account of (masked) priming, evidence is task-dependent and is dictated by the decision required to the target. In the case of semantic categorization, the evidence consists of distributed semantic features that are diagnostic of category membership: For example, in an “Is it a living thing?” decision, semantic features like <builds nests> and <moves> will contribute positive evidence; In contrast, semantic features such as <is static>, and <made of metal> would contribute evidence against the decision (see e.g., McRae & Boisvert, 1998).

The idea that categorization decision is based on distributed semantic features is well accepted in the semantic memory literature. In category verification (“is X a bird?”), a typical exemplar (e.g., *robin*) is verified more quickly than an atypical exemplar (e.g., *ostrich*). Rosch and Mervis (1975) showed that typicality ratings are highly correlated with the number of features shared by the exemplars (i.e., family resemblance). These results are consistent with our assumption that in semantic categorization, the evidence that drives the decision is semantic features that are diagnostic of category membership.

Further empirical support for the assumption that categorization decision is based on distributed semantic features can be found in more recent studies of the *semantic richness effect*. This effect refers to the finding that in many experimental tasks (lexical decision, concreteness decision), participants respond more quickly to words for which people can generate more semantic features (e.g., Pexman, Holyk, & Monfils, 2003; Pexman, Lupker, & Hino, 2002). Grondin, Lupker, and McRae (2009) investigated what types of semantic features were important in driving the semantic richness effect and found that features shared by numerous concrete concepts such as <has four legs> facilitated decisions to a greater extent than do distinctive features that are idiosyncratic to the concept such as <moos>. Their explanation of this effect is that the features shared by many members of the category are diagnostic of the category: shared features are “better cues to concreteness because they better cue the fact that the word refers to something that is a member of the large category of concrete objects” (Grondin et al., 2009, p.15).

This view of semantic categorization has an important implication for our account of priming. It means that for a large category like "living things" used here, which comprises many subcategories like birds, mammals, fish, and insects, the semantic features that are diagnostic of category membership are not uniform, but diverse. For example, in the case of *EAGLE*, features such as <flies> and <is a carnivore> would indicate that it is a predatory bird, whereas in the case of *SEAL*, features like <swims>, <eats fish>, and <has fur> would indicate that it is a water-dwelling mammal. This would explain why the size of priming was much greater for the semantically related prime–target pairs such as *hawk–EAGLE* used in Experiment 1 than the merely category-congruent pairs such as seal-EAGLE used in Experiment 2. By design, the semantically related pairs were selected to have many semantic features in common, whereas the category-congruent pairs were not. The features of the target that are diagnostic of category membership are therefore more likely to be possessed by the semantically-related prime than the merely category-congruent prime, and hence the contribution of the prime toward the correct decision for the target—that is, the priming effect—is much greater for the former.

RT Distribution Analyses

In the discussion presented so far, we focused on the mean RT, as in most previous studies of semantic priming. However, there is a growing recognition that an analysis of mean RTs does not tell a full story, and researchers have begun to examine the whole RT distribution when investigating semantic priming (e.g., Balota, Yap, Cortese, & Watson, 2008; Gomez, Perea, & Ratcliff, 2013; Thomas, Neely, & O'Connor, 2012). One reason for this is that RT distributions are positively skewed and hence a difference (or lack thereof) between mean RTs can be misleading (see, e.g., Heathcote, Popiel & Mewhort, 1991, for an example concerning the Stroop effect). More important for the present purposes, RT distribution analyses have the potential to reveal the nature of the mechanism underlying the effect in question by providing a richer picture of how the effect changes over time.

One method for visualising the RT distribution is quantile plots (see the Results section below for further details). In this method, RT data for individual participants are organised from fast to slow for each condition (here, the related prime condition vs. the unrelated prime condition) and are then divided into equal-sized portions, called quantiles or bins, that contain for example the fastest 25% of RTs, the next fastest 25%, and so on. The RTs are then plotted across the quantiles, one for each condition. The difference between these two distributions reflects the size of the priming effect. Plotting the data across the quantiles shows how the priming effect may change over time, thereby giving a richer picture of the underlying mechanisms of semantic priming effects than the mean RTs.

What are the patterns of quantile plots expected for the semantic priming effect (found in Experiment 1) and the category congruence effect (found in Experiment 2)? For the former, on the basis of the view that priming reflects source confusion in the evidence accumulation process, what we expect is a head-start pattern—namely, there should be a constant-size semantic priming effect across the quantiles. It is of interest to note that this head-start pattern was observed by Gomez et al. (2013) in their masked priming lexical decision experiment with “identity” primes (e.g., *house*–*HOUSE*). This is consistent with Norris and Kinoshita’s (2008) account of masked priming, which explains the effect in terms of source confusion in the evidence accumulation process. In masked priming, no prime discounting occurs because the prime is masked and hence the participants are unaware that the evidence accumulated from the prime comes from a difference source. (See Kinoshita & Norris, 2010, for evidence that prime diagnosticity modulated the size of identity priming effect when the prime was visible but not when it was masked.)

There are two ways in which this head-start pattern could be modulated by the RP manipulation. One suggests a late locus of the RP effect. According to the ROUSE model (Huber et al., 2001), source confusion is automatic, but the discounting process that occurs in accordance with prime diagnosticity modulates the net priming effect. In a low RP condition, prime evidence should be discounted more, and in the high RP condition less (Weidemann et al., 2008). It should be noted that the ROUSE model was developed for the perceptual identification task, and it has not been applied to RT data. It is important to point out that the late-locus scenario is therefore not a direct prediction of the ROUSE model, but what may be expected from the model on the assumption that the discounting process follows an obligatory accumulation of evidence from the prime (source confusion). We believe this assumption is reasonable, and point out that Pratte, Rouder, Morey and Feng (2010, see p.2016) offered a similar interpretation of the prime discounting process in the ROUSE model. According to this view, the RP manipulation is expected to modulate priming effects in later quantiles. Specifically, in the earliest quantile, reflecting the automatic source confusion, semantic priming effects are expected to be equal in size in the high and low RP conditions; in the later quantiles, more prime discounting occurs in the low RP condition, resulting in a smaller net semantic priming effect than in the high RP condition.

Although the above interpretation of the discounting process suggests a late locus of RP effects, an alternative scenario, with an early locus, is also possible. According to this scenario, the RP manipulation affects the amount of perceptual "filtering", similar to the notion of early bottleneck suggested in bottleneck models of attention (e.g., Broadbent, 1958; Treisman, 1960). The idea of an early locus is borrowed from an account of the Stroop interference effect proposed by Monsell, Taylor and

Murphy (2001). They suggested that in the Stroop colour naming task, attentional control may be exerted *late*, to reduce the competition between *individual responses* (reading aloud the specific carrier word e.g., "*sky*" vs. saying the specific colour name e.g., "yellow"), or *early*, to reduce the competition between the parts of the task set (word reading vs. colour naming). Monsell et al. noted that a late-selection mechanism "inherits the problem… of specifying how the late selection process knows which is the right response among those activated. It would seem necessary for each activated response tendency to be tagged with, or linked to, its sensory source of activation, in a way that can be "inspected" by the response selection process. The virtue of an early selection mechanism is that much of the work of action selection is done at the perceptual level" (p. 148). Applying the early-locus filtering notion to the present priming paradigm suggests then that the RP manipulation modulates the task set of reading the prime as against the target, modulating the amount of source confusion. The filtering of the prime would be based on perceptual cues that distinguish between the prime and target, for example, the temporal cue (the prime is presented shortly after the fixation signal, before the target) and visual cues (e.g., the prime is presented in lowercase letters and the target is presented in uppercase letters). Because of its early locus, the filtering of prime processing would have an effect of reducing the size of semantic priming effect right from the earliest quantile in the low RP condition, with the size of the effect remaining consonant across the quantiles in both the high and low RP conditions.

Turning to Experiment 2, the predicted pattern of the category-congruence effect across quantiles is quite different from that for Experiment 1. The mean RT analysis of Experiment 2 has indicated that the category congruence effect was a response cuing effect. Previous studies of response priming have shown that the effect decreases across quantiles. For example, in a "Bigger-than-5?" task, using digit stimuli, Kinoshita and Hunt

(2008) found that the congruence effect with (masked) primes that have been used as targets (and hence produces priming via learned stimulus-response mapping) declined across quantiles. The same pattern is observed with the Simon task (e.g., Pratte, et al., 2010; Ridderinkoff, 2002), in which the location of the presented stimulus cues the required spatial response (e.g., left or right button). This declining pattern of response priming across quantiles (i.e., an underadditive interaction between the effect and quantiles) is explained in terms of a motor response that is rapidly activated, and decays (or suppressed) over time. Thus, on the assumption that the positive category-congruence effect observed in the high proportion condition is a response cuing effect, the predicted pattern is that the congruence effect should decline across quantiles. In the low proportion condition, a reverse (negative) congruence effect was found, and this was explained in terms of participants predicting the opposite response to the prime. On the assumption that intentionally generating a response takes time (e.g., Neely, 1977, in which participants were told to expect the target to be a part of a body given the prime *BUILDING*), in this case, the reversed congruence effect is expected to increase over the quantiles.

Results

All correct RTs were analysed using QMPE (version 2.18) software developed by Cousineau, Brown, and Heathcote (2004) available at http://www.newcl.org/software/qmpe.htm. QMPE outputs quantile estimates, which are variable-width histogram estimators, used to plot the RT distribution. For each participant, RTs were sorted from fastest to slowest per condition and divided into four equal-sized bins (fastest 25%, next fastest 25%, etc.). The observed quantile estimates generated by QMPE correspond to the average of the last trial of the lower quantile and the first trials of the higher quantile. RT data therefore do not have to be trimmed for outliers, as the last trial of the highest quantile does not affect the observed estimate for the last quantile (only the first trial of this last quantile is used). These quantile estimates were then averaged over participants and plotted per condition.

In the present analysis, for each of Experiments 1 and 2, we analysed the RTs from the correct trials as a 4 (Quantile) x 2 (prime relatedness: related vs. unrelated) factorial design, separately for the low and high RP conditions. The main result of interest is the linear quantile x prime relatedness interaction, showing how the semantic priming effect or category congruence effect increases or reduces, respectively, across quantiles.

Experiment 1. The quantile plots for Experiment 1 are shown in Figure 1. In the low RP condition, averaged over the quantiles, the main effect of prime relatedness was non-significant, ($F(1,29) = 2.86$, p =.102, η^2=.090), consistent with the non-significant semantic priming effect in the mean RT analysis. The magnitude of the (null) semantic priming effect did not change over RT bins, as indexed by the non-significant interaction between the Relatedness factor and the linear trend of the Quantile factor ($F(1,29)$ = 0.14, p =.713, η^2= .005). In the high RP condition, the main effect of Prime relatedness was highly significant ($F(1,29) = 77.93$, p <.001, η^2=.729), consistent with the analysis of mean RT. As in the low RP condition, the interaction between the linear trend of the Quantile factor and prime relatedness was non-significant ($F(1,29) = 3.05$, p =.091, η^2= .095) indicating a constant semantic priming effect across quantiles.

Experiment 2. The quantile plots for Experiment 2 are shown in Figure 2. For the low RP condition, averaged across the quantiles, the effect of prime relatedness was significant ($F(1,27)$=13.91, p = .001, η^2 = .340), reflecting an overall congruency *disadvantage*. It is important to note that there was a significant interaction between prime relatedness and the linear trend contrast of the Quantiles factor ($F(1,27)$=8.05, p = .009, η^2 = .230). As can be seen in the top panel of Figure 2, this reflected an increasing congruency disadvantage over the quantiles. For the high RP condition, averaged over the quantiles, the category congruence effect was non-significant ($F(1,27)=2.03$, p = .166, η^2 = .070). The interaction between prime relatedness and the linear trend of the Quantiles factor approached significance ($F(1,27)=3.63$, p = .068, η^2 = .118). As the bottom panel of Figure 2 shows, the category congruence effect tends to diminish across quantiles.

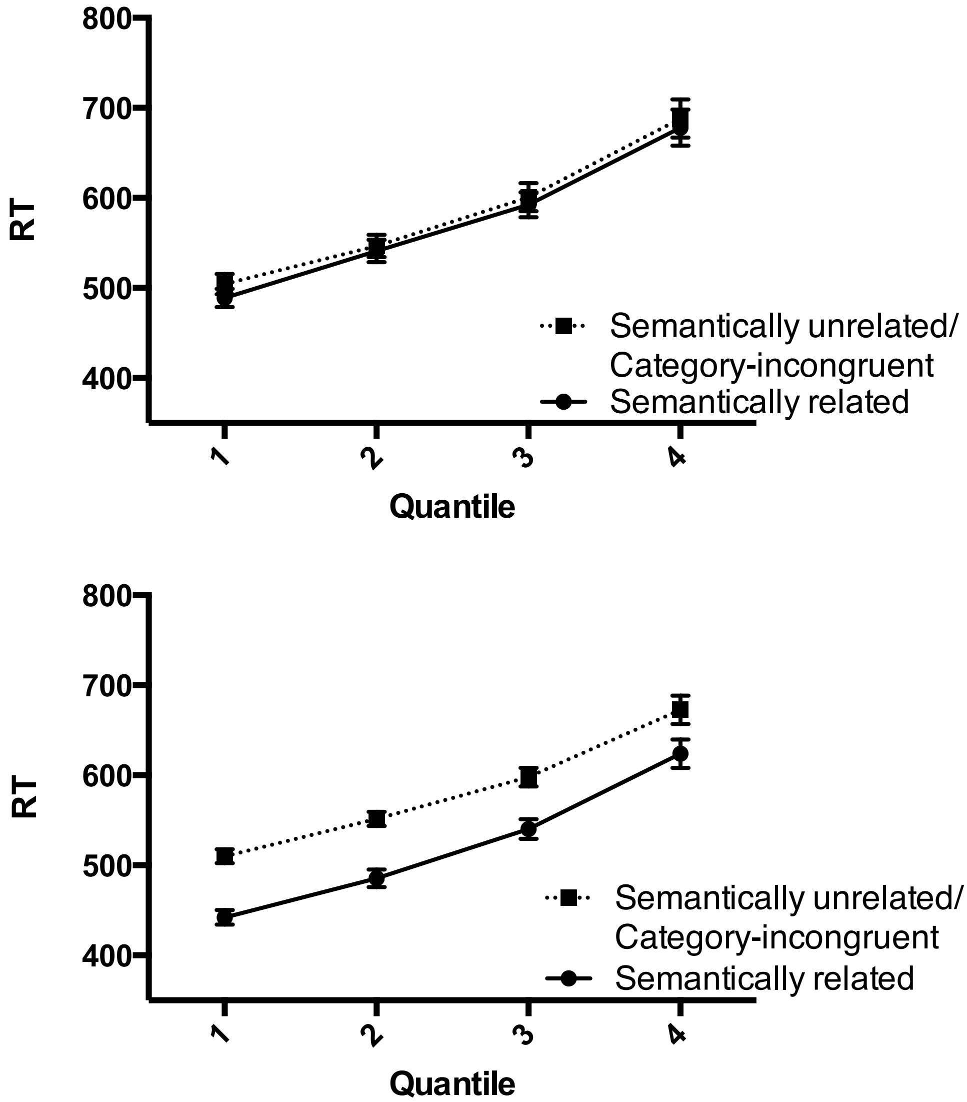

Figure 1. RT distribution of Experiment 1. Top panel = low relatedness proportion (RP) condition; bottom panel = high RP condition. Error bars represent the standard error of the mean.

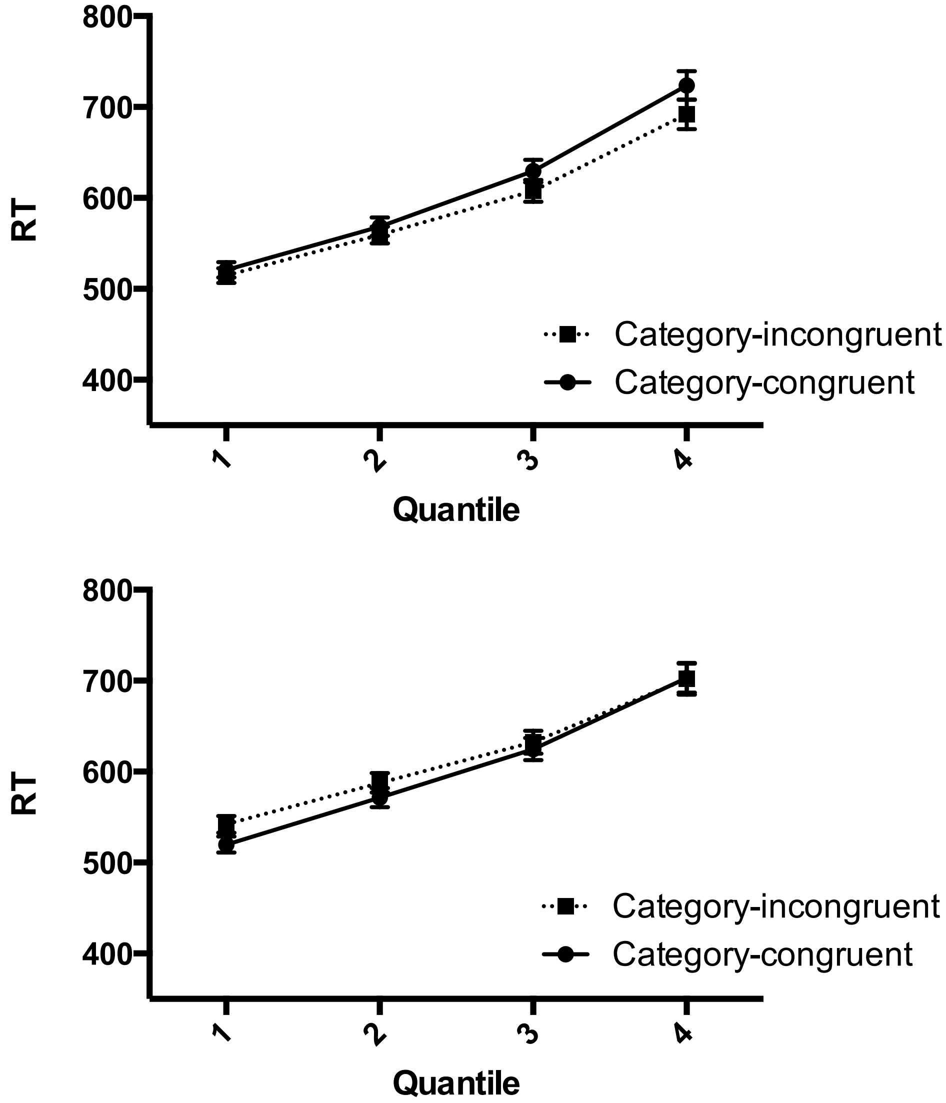

Figure 2. RT distribution of Experiment 2. Top panel = low congruency proportion condition; Bottom panel = high congruency proportion condition. Error bars represent the standard error of the mean.

Discussion

In Experiment 1, the pattern of semantic priming effect showed a head-start pattern – a constant-size effect across the quantiles. The RP manipulation did not modulate this pattern; rather, it magnified the semantic priming effect from the earliest quantiles, which remained constant across all quantiles. The RT distribution data are therefore consistent with the filtering interpretation of RP effect with an early locus, rather than the discounting account with a late locus, as might be expected from Huber et al. (2001) and Weidemann et al. (2008).

According to the discounting account, the RP effect is explained in terms of prime discounting when combining the evidence from the prime leads to the wrong decision for the target most of the time, as in the low RP condition. Evidence discounting decreases the priming effect, by "throwing away" the evidence that has come from the prime. According to this late-locus account, the prime discounting process follows an initial accumulation of evidence from the prime (reflecting source confusion), so it should affect the later quantiles. In the low RP condition, more discounting occurs, so the semantic priming effect should diminish across the quantiles. This is clearly not the pattern obtained in Experiment 1. Rather, the low RP reduced the size of the semantic priming effect right from the earliest quantiles, suggesting an early locus, like an attentional filter (cf. Broadbent, 1958) suggested in the early selection models of attention. The filter may be applied on the basis of perceptual cues that distinguish between the prime and the target, for example, the temporal cue (the prime is presented immediately after the fixation signal, shortly before the target) and visual cues (e.g., the prime is presented in lowercase letters, the target is presented in uppercase letters).

In addition, the RT distribution pattern of Experiment 1 was quite different from that found in Experiment 2, providing further evidence that the semantic priming effect in Experiment 1 is not due to response cuing. In the high RP condition, the response to the target is the same as that for the prime on 75% of the trials; in the low RP condition, the response to the target is the opposite of the prime on 75% of the trials. Consistent with the view that the response *opposite* to that of the prime was predicted intentionally in the low RP condition, in Experiment 2, congruent disadvantage (i.e., advantage to the category-incongruent targets, e.g., *rifle–EAGLE*) increased over quantiles. In contrast, in the low RP condition in Experiment 1, neither a relatedness disadvantage nor an increase in relatedness disadvantage over quantiles was observed. In the high RP condition in Experiment 2, there was a trend toward the congruent advantage to decline over quantiles. Such a pattern was expected from the view that a rapidly (and automatically) activated motor response either decays or is suppressed over time (e.g., Pratte, et al., 2010; Ridderinkoff, 2002). In contrast, in Experiment 1, a large semantic priming effect was maintained across the quantiles.

General Discussion

The present study investigated the automaticity of semantic priming effects using a semantic categorization task ("Is this an animal (living thing)?") manipulating the proportion of related trials (relatedness proportion, RP) at a short prime–target SOA (240 ms). Consistent with Neely et al. (1989), we have argued that in previous lexical decision experiments, RP was confounded with nonword ratio, which could produce a semantic priming effect via the post-lexical coherence checking strategy. In a semantic categorization task, this concern does not arise, and the possible involvement of a post-lexical coherence checking strategy can be ruled out. On the assumption that at a short SOA semantic priming effects are produced by an automatic spreading activation process, there should be no RP effect in a semantic categorization task. In direct contradiction of this assumption, a robust RP effect was found in Experiment 1: In the condition containing a high proportion (.75) of related trials, the semantic priming effect (58 ms) was more than five times greater than the semantic priming effect in the low proportion (.25) condition.

In Experiment 1, the related prime–target pairs shared many semantic features, for example, *hawk*–*EAGLE* and *sofa*–*COUCH*, as well as being category-congruent. In order to test the possibility that the semantic priming effect observed in Experiment 1 was due to response cuing (the category-congruent primes cuing the category or response to the target), Experiment 2 used category-congruent but semantically unrelated pairs (e.g., *seal–EAGLE, rifle–COUCH*), and manipulated the proportion of category-congruent trials. Experiment 2 produced a very different pattern of results from that of Experiment 1: Here, in the high RP condition, a small category congruence effect (13 ms advantage to category-congruent prime condition) was observed, and in the low RP condition, the effect was reversed (producing an advantage for the category-incongruent prime condition). This pattern is what is expected if the prime category/response is used to predict the target category/response, as the prime reliably predicts the target category/response on 75% of the trials in the low RP condition (predicting the opposite response to the prime) as well as in the high RP condition. The dissociation between the results of Experiments 1 and 2 was taken as evidence that the semantic priming effect observed in Experiment 1 cannot be explained simply in terms of a response cuing mechanism due to category congruence.

These findings, together with the robust RP effects, challenge the notion that the semantic priming effects observed at the short SOA are due to an automatic spreading activation process. Instead, following Huber et al. (2001), we hypothesized that the priming effects are best explained in terms of evidence accumulation and source confusion. In semantic categorization, evidence is in the form of semantic features that are diagnostic of category membership. Because of its temporal and spatial proximity to the target, evidence is accumulated from the prime and is combined with the evidence for the target (i.e., there is source confusion). This source confusion leads to positive semantic priming effects: The related prime (e.g., *hawk–EAGLE; sofa–COUCH*), which has similar semantic features as the target, gives a head-start.

On the assumption that prime discounting occurs in accordance with RP following automatic source confusion, it was expected that the semantic priming effects in the early quantiles should be similar in the high- and low RP conditions, and differ only in the later quantiles, with the effect diminishing in the low RP condition. The RT distribution data did not support this expectation. Instead, the data showed that the RP affected the size of semantic priming effect right from the earliest quantiles, and remained constant across the quantiles. We took this pattern as an implication of an early locus of the RP effect, like an attentional filter (cf. Broadbent, 1958) suggested in the early selection models of attention. Our working assumption is that the filter is applied on the basis of perceptual cues that distinguish between the prime and target (e.g., the prime is presented in lowercase letters, the target is presented in uppercase letters) to reduce source confusion in the low RP condition. This early locus of RP effect revealed by the RT distribution further argues against the view that an *automatic* spreading activation process was responsible for the semantic priming effect.

Conclusion

A semantic activation process that spreads *automatically* from the prime to the target has been a standard explanation of semantic priming effects found at short SOAs. The present finding of a robust RP effect challenges this view, and we suggested instead that the notions of evidence accumulation and source confusion provide a more coherent account of semantic priming effects in a semantic categorization task. This interpretation was supported further by the head-start pattern of semantic priming effects in the RT distribution data. Future work should test further predictions of the account regarding task dependence (the nature of evidence to be accumulated is dictated by the task, and hence the account predicts the semantic priming effect should be task-dependent) and the dissociation between masked and unmasked priming which distinguish the account from the automatic spreading activation account.

References

Antos, S. J. (1979). Processing facilitation in a lexical decision task. *Journal of Experimental Psychology, 5*, 527-545.

Balota, D. A., Yap, M. J., Cortese, M. J., & Watson, J. M. (2008). Beyond mean response latency: Response time distributional analysis of semantic priming. *Journal of Memory and Language, 59*, 495-523.

Broadbent, D. E. (1958). *Perception and communication*. New York: Oxford University Press.

Brysbaert, M., & New, B. (2009). Moving beyond Kuçera and Francis: A critical evaluation of current word frequency norms and the introduction of a new and improved word frequency measure for American English. *Behavior Research Methods, 41*, 977-990.

Collins, A. M., & Loftus, E. F. (1975). A spreading-activation theory of semantic processing. *Psychological Review, 82*, 407-428.

Cousineau, D., Brown, S. [D.], & Heathcote, A. (2004). Fitting distributions using maximum likelihood: Methods and packages. *Behavior Research Methods, Instruments, & Computers,* 36, 742-756.

De Groot, A. M. B. (1984). Primed lexical decision: Combined effects of the proportion of related prime–target pairs and the stimulus-onset asynchrony of prime and target. *The Quarterly Journal of Experimental Psychology Section A, 36*, 253-280.

Forster, K. I., & Forster, J. C. (2003). DMDX: A windows display program with millisecond accuracy. *Behavior Research Methods, Instruments, and Computers, 35*, 116-124.

Gomez, P., Perea, M., & Ratcliff, R. (2013). A diffusion model account of masked vs. unmasked priming: Are they qualitatively different? *Journal of Experimental Psychology: Human Perception and Performance*, *39,* 1731-1740.

Grondin, R., Lupker, S.J., & McRae, K. (2009). Shared features dominate semantic richness effects for concrete concepts. *Journal of Memory and Language, 60*, 1-19.

Heathcote, A., Popiel, S. J., & Mewhort, D. J. K. (1991). Analysis of response time distributions: An example using the Stroop task. *Psychological Bulletin, 109*, 340-347.

Huber, D. E., Shiffrin, R. M., Lyle, K. B., & Ruys, K. I. (2001). Perception and preference in short-term word priming. *Psychological Review, 108*, 149-182.

Hutchison, K. A. (2007). Attentional control and the relatedness proportion effect in semantic priming. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 33*, 645-662.

Kinoshita, S., & Hunt, L. (2008). RT distribution analysis of category congruence effects with masked primes. *Memory & Cognition, 36*, 1324-1334.

Kinoshita, S., Mozer, M. C., & Forster, K. I. (2011). Dynamic adaptation to history of trial difficulty explains the effect of congruency proportion on masked priming. *Journal of Experimental Psychology: General, 140*, 622-636.

Kinoshita, S., & Norris, D. (2010). Masked priming effect reflects evidence accumulated by the prime. *Quarterly Journal of Experimental Psychology, 63*, 194-204.

Landauer, T. K., McNamara, D.S., Dennis, S., & Kintsch, W. (2007). *Handbook of Latent Semantic Analysis.* Mahwah, NJ: Lawrence Erlbaum Associates, Publishers.

Masson, M. E. J. (1995). A distributed memory model of semantic priming. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 21*, 3-23.

McNamara, T. P. (2005). *Semantic priming: Perspectives from memory and word recognition.* New York: Psychology Press.

McRae, K., & Boisvert, S. (1998). Automatic semantic similarity priming. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 24*, 558-572.

McRae, K., Cree, G., Seidenberg, M., & McNorgan, C. (2005). Semantic feature production norms for a large set of living and nonliving things. *Behavior Research Methods, 37*, 547-559.

McRae, K., de Sa, V. R., & Seidenberg, M. S. (1997). On the nature and scope of featural representations of word meaning. *Journal of Experimental Psychology: General, 126*, 99-130.

Meyer, D. E., & Schvaneveldt, R. W. (1971). Facilitation in recognizing pairs of words: Evidence of a dependence between retrieval operations. *Journal of Experimental Psychology, 90*, 227-234.

Monsell, S., Taylor, T.J., & Murphy, K. (2001). Naming the color of a word: Is it responses or task sets that compete? *Memory & Cognition, 29*, 137-151.

Neely, J. H. (1977). Semantic priming and retrieval from lexical memory: Roles of inhibitionless spreading activation and limited-capacity attention. *Journal of Experimental Psychology: General, 106*, 226-254.

Neely, J. H. (1991). Semantic priming effects in visual word recognition: A selective review of current findings and theories. In D. Besner & G.W. Humphreys (Eds.), *Basic processes in reading: Visual word recognition* (pp. 264-336). Hillsdale, NJ: Erlbaum.

Neely, J. H., & Keefe, D. E. (1989). Semantic context effects on visual word processing: A hybrid prospective/retrospective processing theory. In G.H. Bower, (Ed.), *The psychology of learning and motivation: Advances in research and theory,* Vol. 24 (pp. 207-248). New York: Academic Press.

Neely, J. H., Keefe, D. E., & Ross, K. L. (1989). Semantic priming in the lexical decision task: Roles of prospective prime-generated expectancies and retrospective semantic matching. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 15*, 1003-1019.

Norris, D. (1984). The mispriming effect: Evidence for an orthographic check in the lexical decision task. *Memory & Cognition, 12*, 470-476.

Norris, D., & Kinoshita, S. (2008). Perception as evidence accumulation and Bayesian inference: Insights from masked priming. *Journal of Experimental Psychology: General, 137*, 434-455.

O'Connor, R. E., & Forster, K. I. (1981). Criterion bias and search sequence bias in word recognition. *Memory & Cognition, 9*, 78-92.

Pexman, P., Holyk, G., & Monfils, M.H. (2003). Number-of-features effects and semantic processing. *Memory & Cognition, 31*, 842-855.

Pexman, P., Lupker, S., & Hino, Y. (2002). The impact of feedback semantics in visual word recognition: Number-of-features effects in lexical decision and naming tasks. *Psychonomic Bulletin & Review, 9*, 542-549.

Plaut, D. C., & Booth, J. R. (2000). Individual and Developmental Differences in Semantic Priming: Empirical and Computational Support for a Single-Mechanism Account of Lexical Processing. *Psychological Review, 107*, 786-823.

Posner, M. I., & Snyder, C. R. R. (1975). Attention and cognitive control. In R.L. Solso (Ed.), *Information processing and cognition: The Loyala symposium* (pp. 55-85). Hillsdale, NJ: Lawrence Erlbaum Associates, Inc.

Pratte, M. S., Rouder, J. N., Morey, R. D., & Feng, C. (2010). Exploring the differences in distributional properties between Stroop and Simon effects using delta plots. *Attention, Perception & Psychophysics, 72*, 2013-2025.

Ridderinkoff, K. R. (2002). Activation and suppression in conflict tasks: Empirical clarification through distributional analysis. In W. Prinz & B. Hommel (Eds.), *Attention & Performance XIX: Common mechanisms in perception and action* (pp.494-519). Oxford: Oxford University Press.

Rosch, E., & Mervis, C. B. (1975). Family resemblances: Studies in the internal structure of categories. *Cognitive Psychology, 7*, 573-605.

Smith, E. E., Shoben, E. J., & Rips, L. J. (1974). Structure and process in semantic memory: A featural model for semantic decisions. *Psychological Review, 81*, 214-241.

Thomas, M. A., Neely, J. H. & O'Connor, P. (2012). When word identification gets tough, retrospective processing comes to the rescue. *Journal of Memory and Language, 66*, 623-643.

Treisman, A. (1960). Contextual cues in selective listening. *Quarterly Journal of Experimental Psychology, 12*, 242-248

Tweedy, J., Lapinski, R., & Schvaneveldt, R. (1977). Semantic-context effects on word recognition: Influence of varying the proportion of items presented in an appropriate context. *Memory & Cognition, 5*, 84-89.

Weidemann, C. T., Huber, D. E., & Shiffrin, R. M. (2008). Prime diagnosticity in short-term repetition priming: Is primed evidence discounted, even when it reliably indicates the correct answer? *Journal of Experimental Psychology: Learning, Memory, and Cognition, 34*, 257-281.

Appendix

List of Critical Stimuli

Stimuli are listed in the order: semantically related prime (used in Experiment 1); semantically unrelated and category-congruent prime (used in Experiment 2), category-incongruent prime, target in capital letters.

Animals (Living Things)

Gorilla, peacock, microscope, CHIMPANZEE; moth, alligator, cathedral, BUTTERFLY; alligator, stork, accordion, CROCODILE; wallaby, whale, necklace, KANGAROO; whale, gorilla, guitar, DOLPHIN; bison, frog, trumpet, BUFFALO; peacock, wallaby, trailer, PHEASANT; hyena, dove, ashtray, COYOTE; cheetah, duck, shelves, LEOPARD; stork, cheetah, fridge, PELICAN; seal, moth, mirror, WALRUS; trout, hawk, crown, SALMON; dove, dog, toilet, PIGEON; lamb, trout, ruler, SHEEP; frog, bee, door, TOAD; duck, hyena, chain, GOOSE; hawk, seal, chair, EAGLE; tuna, bison, cage, SARDINE; bee, lamb, doll, WASP; dog, tuna, key, DINGO; iguana, cougar, chandelier, SALAMANDER; beetle, deer, corkscrew, COCKROACH; falcon, horse, microwave, BLACKBIRD; mare, robin, scissors, STALLION; turtle, beetle, football, TORTOISE; hare, falcon, tractor, RABBIT; squid, turtle, sweater, OCTOPUS; robin, mare, cabinet, SPARROW; rat, emu, rifle, MOUSE; emu, beaver, balloon, OSTRICH; cougar, chicken, buckle, PANTHER; lion, skunk, drill, TIGER; deer, squid, razor, MOOSE; chicken, crab, lantern, ROOSTER; horse, lion, fence, PONY; beaver, iguana, flute, OTTER; skunk, ox, church, RACCOON; crown, hare, piano, RAVEN; crab, crow, ball, LOBSTER; ox, rat, bed, COW.

Nonanimals (Man-Made Things)

Airplane, necklace, rattlesnake, HELICOPTER; bungalow, trumpet, woodpecker, APARTMENT; trumpet, bungalow, mackerel, SAXOPHONE; cellar, airplane, flamingo, BASEMENT; necklace, door, catfish, BRACELET; bike, cellar, wallaby, SCOOTER; fridge, guitar, gorilla, FREEZER; spear, shoes, cheetah, HARPOON; gloves, chair, peacock, MITTENS; sled, dish, hyena, SLEIGH; pillow, fridge, camel, CUSHION; shoes, spear, whale, BOOTS; dress, knife, trout, SKIRT; knife, pillow, bison, SWORD; chair, gloves, stork, BENCH; pot, sled, possum, KETTLE; guitar, dress, duck, BANJO; dish, car, swan, BOWL; door, bike, bear, GATE; car, pot, dog, BUS; piano, elevator, cougar, KEYBOARD; flute, drapes, scorpion, CLARINET; cabinet, flute, platypus, CUPBOARD; pants, church, chicken, TROUSERS; elevator, cabinet, penguin, ESCALATOR; mixer, hut, seagull, BLENDER; hut, pants, iguana, COTTAGE; shawl, desk, deer, SCARF; jar, shawl, toucan, BOTTLE; drapes, ship, sealion, CURTAINS; rifle, cart, beetle, PISTOL; desk, spade, wombat, BUREAU; church, fork, falcon, CHAPEL; spade, oven, turtle, SHOVEL; fork, piano, leech, SPOON; ship, sofa, bunny, YACHT; cart, mixer, ibis, WAGON; oven, van, horse, STOVE; van, jar, robin, TRUCK; sofa, rifle, squid, COUCH.

Chapter 3—An RT Distribution Analysis of Relatedness Proportion Effects in Lexical Decision and Semantic Categorization Reveals Different Mechanisms

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An RT Distribution Analysis of Relatedness Proportion Effects in Lexical Decision and Semantic Categorization Reveals Different Mechanisms

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Abstract

The magnitude of the semantic priming effect is known to increase as the proportion of related trials in an experiment increases. This relatedness proportion (RP) effect was studied in a lexical decision task at a short prime–target SOA (240 ms), which is widely assumed to preclude strategic prospective usage of the prime. The analysis of RT distribution suggested that the observed RP effect reflected a modulation of a retrospective semantic matching process. The pattern of RP effect on RT distribution found here is contrasted to that reported in De Wit and Kinoshita's (2014) semantic categorization study, and it is concluded that the RP effect is driven by different underlying mechanisms in lexical decision and semantic categorization.

Keywords: semantic priming; relatedness proportion, RT distribution analysis; lexical decision, retrospective semantic matching

Introduction

The size of the semantic priming effect increases when the proportion of related prime–target pairs in the experimental list increases. This finding, first reported by Tweedy, Lapinski, and Schvaneveldt (1977), is referred to as the Relatedness Proportion (RP) effect, and is generally taken as an indicator of strategic use of the prime. The standard explanation of the RP effect is in terms of the expectancy generation strategy. Specifically, participants generate expectancies regarding the identity of the target based on the semantic properties of the prime (Neely, 1977; Becker, 1980), and they are more likely to do so when the proportion of related prime–target pairs is high and hence the expectation is likely to be correct on most trials. Consistent with the assumption that it takes time to generate expectancies, reliable RP effects are generally found only at long prime–target SOAs (see Hutchison, 2007 for a review). As noted by Hutchison, Neely, and Johnson (2001) "when the SOA is short (under 300 ms), RP often has little or no effect on semantic priming (p. 1451)". Based on the two-process model of semantic priming (Posner & Snyder, 1975; Neely, 1977; 1991) which explains semantic priming effects in terms of a fast-acting, automatic spreading activation process, and a slow-acting controlled process, it has been widely assumed that semantic priming effects obtained at short SOAs of 250 ms or less reflect the former. There is a growing recognition, however, that this assumption may be incorrect.

One line of evidence comes from studies that found RP effects at short SOAs (e.g., De Groot, 1984; De Wit & Kinoshita, 2014). De Groot (1984) used the lexical decision task and manipulated the proportion of related prime–target pairs (RPs of .25, .50, .75, and 1.00) at different SOAs (240 ms, 540 ms, and 1040 ms). She found robust RP effects at all levels of SOAs, and even at the shortest SOA of 240 ms, which is generally considered too short for the expectancy generation strategy to be used, the size of semantic effect was greater (by 16 ms) in the .75 RP condition than in the .25 RP condition. De Wit and Kinoshita (2014) also manipulated RP (.25 vs. .75 related pairs) at a short SOA of 240 ms, but used a semantic categorization task ("Is it an animal?") instead of a lexical decision task. They too found that the semantic priming effect was larger (by 47 ms) in the high RP than low RP condition.

The present study investigates the mechanism responsible for the RP effect at a short SOA in the lexical decision task using RT distribution analyses, and contrasts it with the effect recently reported with the semantic categorization task (De Wit & Kinoshita, 2014). As will be discussed shortly, an analysis of the RT distribution can be more informative than the analysis of mean RT alone. De Wit and Kinoshita (2014) found that in their semantic categorization task the semantic priming effect was reflected as a shift in the RT distribution, and that the RP manipulation further increased the amount of shift (the theoretical implication of this pattern of RT distribution will be described later in the General Discussion). However, as our review of the literature will show, the extant data indicate that the semantic priming effect on the RT distribution pattern may be different for the lexical decision and the semantic categorization tasks, and consequently, the modulation of the effect by RP may also be task-dependent. The present study investigates this possibility by using the same stimuli used by De Wit and Kinoshita (2014) in a lexical decision task, and by comparing the pattern of RP effects on the RT distribution in the two tasks. First, we review the literature to identify what mechanism is likely to be responsible for the semantic priming effect in lexical decision at a short SOA.

Retrospective Semantic Matching and RP Effects in Lexical Decision

In the lexical decision task, although a short SOA will not allow sufficient time for strategic prospective use of the prime, a different strategic retrospective process may come into play. De Groot (1984) proposed that the RP effects found in her study are driven by such a strategy, a process she called post-lexical coherence checking. It is synonymous with what Neely (1991) termed the retrospective semantic matching strategy.

According to this strategy, *after* the target is presented but before the decision to the target has been completed, the meaning of the target is matched to that of the prime. In the lexical decision task, semantic relatedness of prime and target is indicative of the lexical status of the target, as only word targets are semantically related to the prime. This would be the case as in almost all studies (with the exception of e.g., Antos, 1979, Norris, 1984, O'Connor & Forster, 1981), none of the nonword targets are paired with word primes that are semantically related to a word the nonword resembles (as in e.g., *father–MOHTER; aunt–UMCLE*). This creates a bias in which participants are predisposed toward responding "word" when a semantic relationship can be found between the target and the prime, and "nonword" in the absence of a semantic relationship. The bias increases the net semantic priming effect for word targets as it delays responses to word targets that were preceded by a semantically unrelated prime.

The use of this retrospective semantic matching is tied to the nonword ratio, that is, the proportion of nonwords given an unrelated word prime (Neely, Keefe, & Ross, 1989). When the nonword ratio is high, the absence of a semantic relationship more reliably indicates the target is a nonword, hence the retrospective semantic matching strategy becomes more viable. As noted by Neely et al. (1989), the nonword ratio is typically confounded with RP—when nonword targets are always paired with semantically unrelated word primes, and the number of word and nonword target trials is held constant, an increase in the proportion of related prime–word target pairs (and hence a decrease in the number of unrelated prime–word target pairs) necessarily results in an increase in nonword ratio. The confound was also present in de Groot's (1984) study: As RP increased, so did the nonword ratio. The RP effects reported in her study can thus be explained as nonword ratio effects, with the increase in the size of the semantic priming effect with higher nonword ratio reflecting the increasing reliance on the retrospective semantic matching.[1]

Retrospective Semantic Matching in RT Distribution Analysis

Support for the view that semantic priming effects obtained in lexical decision could be driven by a retrospective semantic matching strategy can be found in recent studies using RT distribution analyses (e.g., Balota, Yap, Cortese, & Watson, 2008; Gomez, Perea, & Ratcliff, 2013; Hutchison, Heap, Neely, & Thomas, 2014; Thomas, Neely, & O'Connor, 2012; Yap, Balota, & Tan, 2013).

Because RT distributions are almost always positively skewed, analysing the whole RT distribution gives a more complete picture of semantic priming effects than relying on the mean RT alone (see Balota & Yap, 2011, for a summary of the benefits of RT distribution analysis). As pointed out by Pratte, Rouder, Morey and Feng (2010), an effect on the mean RT may be manifested in the RT distribution in different ways. An experimental manipulation can produce an overall distributional shift, where the target manipulation has a constant effect throughout the whole RT distribution, or it can affect the skew of the RT distribution, or both. These different effects on the RT distribution can be captured by alternative methods. One method is quantile plots. In this method, for each of the related and unrelated prime conditions RT data are ordered from the fastest to the slowest, and then divided into equal-sized portions (RT bins), called quantiles. The average of the last trial of the faster RT quantile and the first trial of the

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[1] It is relevant to note that the variation in nonword ratio that accompanies the manipulation of RP is less extreme (assuming an equal number of word and nonword trials). For example, the RP of .75 vs. .25 corresponds to the nonword ratio of .80 vs. .57, and the RP of .25 vs. .50 corresponds to the nonword ratio of .57 vs. .67. This may explain why a RP effect has not been found consistently in lexical decision with short SOAs (see Hutchison, 2007, Table 1).

slower RT quantile make up the quantile estimate, and these quantile estimates are then plotted separately for different conditions.[2] A distributional shift can be seen in quantile plots as a constant effect of the manipulation throughout the quantiles. An effect on the skew of the RT distribution, on the other hand, can be seen in quantile plots as an overadditive or underadditive interaction between quantiles and the effect in question.

In another method, RT distributions are fitted to a specific mathematical function, the ex-Gaussian being the most common (Heathcote, Popiel & Mewhort, 1991; Balota & Yap, 2011). The ex-Gaussian is the convolution (a mathematical combination) of a Gaussian and an exponential distribution. The mode and standard deviation of the Gaussian component are approximated by the μ (mu) and σ (sigma) parameters respectively, and the exponential function is summarized by the τ (tau) parameter, which reflects the mean and standard deviation of the exponential component. Although some (e.g., Hohle, 1965) have argued that the parameters of the ex-Gaussian distribution may be mapped onto underlying theoretical processes (with the Gaussian component mapping onto perceptual/motor processes and the exponential component mapping onto decisional stages), the parameters have also been used simply as summary statistics, and this is the way we use them here. In these parameters, a simple shift in RT distribution, equivalent to a constant effect of a manipulation throughout the quantiles, is reflected in a change in μ alone. In contrast, a stretching of the tail of RT distribution, as would be seen in an overadditive interaction between quantiles and the effect of manipulation (i.e., an increasing effect in the slower quantiles) is reflected in an increase in τ.

Both Gomez et al. (2013) and Balota et al. (2008, Experiment 2 and 3) found that in lexical decision with short SOA (using the RP of .5, i.e., an equal number of related and

[2] Another related measure is a vincentile, which is the average of each RT bins. Quantile plots and vincentile plots are generally very similar.

unrelated prime–target pairs), the size of the semantic priming effect increased across the quantiles.[3] Balota et al. suggested this overadditive interaction between the semantic priming effect and quantiles reflects a retrospective prime retrieval process. Specifically, at the short SOA, there may be two sources of information that drive lexical decisions: One that drives the decision for the target in the unrelated or unprimed conditions, and the influence of the prime. According to Balota et al., as more time becomes available to process the prime, as for the trials represented in the slower quantiles, prime information will have a greater effect on the decision to the target, hence increasing the size of the semantic priming effect.

Thomas et al. (2012) provided direct evidence that the increase in the size of the semantic priming effect in the slow tail of the RT distribution reflects the retrospective use of the prime (the prime–target SOA used by Thomas et al. was longer, at 800 ms). To distinguish prospective processes like expectancy generation from retrospective processes like the semantic matching strategy, they manipulated the direction of prime–target association. In word association production tasks in which subjects are asked to give the first word to come to mind when given a cue, the cue *keg* often elicits *beer* but the cue *beer* does not elicit the response *keg*. That the prime–target pairs that have only backward association (e.g., *beer–keg; cut–crew*) produce semantic priming effects in lexical decision but not in pronunciation task has been taken as evidence for the operation of retrospective semantic matching strategy in lexical decision (Kahan, Neely & Forsythe, 1999; Seidenberg, Waters, Sanders, & Langer, 1984). Thomas et al. used related prime–target pairs that had a forward association only (e.g. *keg–BEER*), a symmetrical association (e.g., *east–west*), or a backward association only (e.g., *small–*

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[3] It should be pointed out that in contrast to this pattern, at the longer SOAs and with clearly presented targets, Balota et al. (2008) found the semantic priming manipulation consistently produced a shift in the RT distribution. This pattern will be discussed in more detail in the General Discussion.

SHRINK). They found an increase in the size of the semantic priming effect in the slow tail of the distribution when a backward association was present in the prime–target pairs (i.e., symmetrical or backward association only pairs), but not when they had only a forward association, and took the results to suggest that the pattern is “produced solely by a retrospective semantic processing mechanism” (p. 630). A similar RT distribution pattern of the backward priming effect was recently reported by Hutchison et al. (2014).

In summary, the existing literature indicates that semantic priming effects found in the lexical decision task using a short prime–target SOA are reflected in an increase in the effect across the quantiles, and that this pattern is identified with the retrospective use of the prime–target relationship.

The Present Experiment

The RT distribution pattern of semantic priming effects observed in the previous lexical decision studies (an increase in the effect across the quantiles) contrasts with the pattern found in semantic categorization by De Wit and Kinoshita (2014). In that study, participants were asked to classify if a word denoted an animal or a nonanimal (manmade things), and the target was preceded by either a semantically related, category-congruent prime (e.g., *hawk–EAGLE, sofa–COUCH*) or a semantically unrelated and category-incongruent prime (e.g., *cart–EAGLE, hyena–COUCH*), with a short prime–target SOA (240 ms). De Wit and Kinoshita further manipulated RP (the high RP condition contained .75 related trials and .25 unrelated trials; the low RP condition contained .25 related trials and .75 unrelated trials), and found that within each RP condition, the size of semantic priming effect was constant across the quantiles. Furthermore, the RP manipulation also had a constant effect across the quantiles: The semantic priming effect in the high RP condition was larger relative to the low RP condition right from the fastest quantiles and remained constant across the quantiles. In other words, in semantic categorization, the semantic priming manipulation produced a shift in the RT distribution, and increasing the proportion of related prime–target pairs further increased the amount of the distributional shift.

Given that the RT distribution patterns of semantic priming effect are different in the two tasks—in lexical decision it is overadditive and in semantic categorization it is constant across the RT distribution—suggesting that the mechanisms driving the semantic priming effects in the two tasks are different, the modulation of semantic effect by RP (i.e., the RP effect) may also be task-dependent. Specifically, unlike the semantic categorization task, increasing the RP in lexical decision may increase the semantic priming effect not by shifting the RT distribution overall, but affecting only the slow tail of the RT distribution. The present experiment tested this by using the same prime–target stimuli used by De Wit and Kinoshita, the same prime–target SOA (240 ms), and also the same RP manipulation (.25 related pairs vs. .75 related pairs), using a lexical decision task.

Method

Participants. Sixty-three undergraduate students of Macquarie University in Sydney, 48 women and 15 men (M_{age} = 22.2 years) enrolled in cognitive psychology courses, participated in the experiment, in return for course credit. All participants had normal or corrected-to-normal vision. Of those, data from 3 participants was excluded due to high (over 20%) error rate.

Design. The experiment used a 2 (RP: low [.25 related] vs. high [.75 related]) x 2 (prime relatedness: semantically related vs. semantically unrelated) factorial design, with RP manipulated between groups and prime relatedness within subjects. The dependent variables were RT and error rate.

Stimuli. The experiment used a lexical decision task. The critical word target items were the same items as used in Experiment 1 of the De Wit and Kinoshita (2014) study (the list of items are presented in the Appendix of that paper) and consisted of 40 animal exemplars (e.g., birds, mammals, marine animals, insects, etc.) and 40 nonanimal exemplars (manmade items like musical instruments, vehicles, tools, etc.). The word targets were on average 6.5 letters long (range 3–10) and had an average Log Subtitle Contextual Diversity value (LgSUBTLCD) of 2.16 (LgSUBTLCD is the Log of the SUBTLEX contextual diversity value, corresponding to the percentages of films containing the word, and is argued by Brysbaert & New (2009) to be the best predictor of lexical decision latency. It is highly correlated with Log word frequency).

In the semantically related prime condition, targets were paired with semantically related primes (e.g., *hawk–EAGLE; sofa–COUCH*). They were identical to the pairs used by De Wit and Kinoshita (2014) and were selected to have high semantic similarity according to the McRae, Cree, Seidenberg, and McNorgan's (2005) semantic feature production norms. The targets were re-paired with category-incongruent primes in the semantically unrelated condition (e.g., *cart–EAGLE; hyena–COUCH*). Primes never occurred as targets. The critical word targets were divided into two sets, matched on mean length, frequency, and similarity. The assignment of lists to the prime conditions was counterbalanced so that each prime and target occurred once in a related pair and once in an unrelated pair across the two lists.

Eighty nonword targets were selected from the English Lexicon Project (ELP) Database (Balota, Yap, Cortese, Hutchison, Kessler, Loftis, et al., 2007, available at http://elexicon.wustl.edu/) to match the critical word targets. All targets were matched on length and orthographic neighbourhood size. The nonword targets had an average accuracy of .80 or higher, as defined by the NWI_Mean_Accuracy attribute in the ELP Database. Each nonword target was paired with a word prime. To ensure that neither animal-ness nor prime-length was an indicator of the target's word status, half of the nonword targets were preceded by an animal prime and the other half by nonanimal (manmade) primes and the prime-length was statistically matched ($t(158) = 0.24$, $p = .814$) between word and nonword targets.

To manipulate RP, 80 filler word trials were used. In the high RP condition, all of these filler prime–target pairs were semantically related and selected to be highly semantically similar. In the low RP condition, the filler prime–target pairs were re-paired to be category-incongruent and semantically unrelated. Because not all word targets appeared in the McRae et al. norms, the average relatedness for the filler pairs was assessed using the Latent Semantic Analysis norms (LSA, Landauer, McNamara, Dennis, & Kintsch, 2007). According to LSA, the average relatedness of the related filler pairs in the high RP condition was .35, which was significantly higher ($t(158) = 12.33$, $p < .001$) than the average relatedness of .08 in the unrelated pairs in the low RP condition. To maintain an equal number of word and nonword targets overall, 80 additional nonword filler targets were selected, matched to the filler targets on length, and paired with word primes. The nonword ratio was therefore .57 (160 nonwords/(40 critical + 80 filler unrelated words + 160 nonwords) in the low RP (.25 related) condition, and .80 (160 nonwords/(40 critical unrelated words + 160 nonwords) in the high RP (.75 related) condition.

The word pairs in the practice phase were comparable to the critical target items used in the test phase. There were 16 practice trials and the first two trials of each block were warm-up trials. Neither the practice nor warm-up trials were included in the analyses.

Apparatus and procedure. Participants were tested individually, or in pairs. The Windows-based DMDX display system (version 4.0.6.0) developed by Forster and Forster (2003) was used for stimulus presentation and data collection. The stimuli were presented on a Samsung LCD monitor, situated approximately 50 cm from the participant. Stimulus display was synchronized to the screen refresh rate (10 ms). Responses were collected with an external response pad with three response keys, of which the two end keys were marked as **+** and **–**.

Each participant completed 320 trials, preceded by 16 practice and 8 warm-up trials, 2 per block. A self-paced break was included after every 80 trials, resulting in 4 blocks. In both RP conditions, the following sequence of presentation was used: a fixation sign (+) was presented for 250 ms, which was followed by the lowercase prime for 200 ms, followed by a 40 ms blank, and then the target. The target remained on the screen until subject's response, and timed out after 2,000 ms. Feedback was given only on trials where participants made an error. Each response was followed by an intertrial interval of 730 ms. If the response was incorrect, the word *wrong* was displayed for 350 ms during the intertrial interval.

At the outset of the experiment, participants were informed they had to categorize the uppercase word as being a word or "not a word". No mention was made of the relatedness of the prime and target. Participants were instructed to keep their index fingers on the two end buttons of the response pad. Participants pressed the + button for word targets and the – button for nonword targets.

Participants received different random orders of trials. Prime and target were presented in the center of the screen in black letters on a white background, using the Courier font, size 11. Feedback was also presented in black, just below of the center of the screen.

Results and Discussion

Error trials were excluded from the RT analysis. To reduce the effect of extremely short and long RTs, RTs greater than or equal to 3 standard deviations from the participant's individual mean RT were replaced by the relevant cut-off value. This affected 1.4% of the trials. A two-way analysis of variance (ANOVA) was used, with the factors prime relatedness (semantically related vs. semantically unrelated) and RP (low [.25 related] vs. high [.75 related]). In the by-subjects analysis (F_1), prime relatedness was a within-subject factor and RP a between-subject factor; in the by-items analysis (F_2), both were within-item factors. An α level of .05 was used. The mean RT, SE and error rates are presented in Table 1.

Table 1.

Summary of results for the lexical decision task, including the mean response latency (RT, in ms), standard errors (in parentheses), percentage error rate (%E), and ex-Gaussian parameters as a function of prime relatedness for both low and high relatedness proportion (RP) conditions as well as the 95% confidence intervals for the semantic priming effects and RP effect.

	RT (*SE*)	%E	μ	σ	τ
			Low RP		
Semantically related	566 (15.64)	5.8	463	30	106
Semantically unrelated	589 (14.89)	7.8	497	46	92
Priming effect	**23 ± 8.1*** **	**2 ± 2.7**	**34 ± 15.5*** **	**16 ± 17.7**	**-14 ± 20.4**
			High RP		
Semantically related	571 (11.99)	6.0	470	43	94
Semantically unrelated	615 (14.97)	9.4	495	41	118
Priming effect	**44 ± 16.1*** **	**3.4 ± 2.4** **	**25 ± 13.4*** **	**-2 ± 14.0**	**24 ± 22.3* **
RP effect	**21 ± 18.0* **	**1.4 ± 3.5**	**-9 ± 20.0**	**-18 ± 21.9**	**38 ± 29.7* **

Note. RT = reaction time. RP effect refers to the semantic priming x RP interaction.
*** $p < .001$; ** $p < .01$; * $p < .05$.

Mean RT. The overall semantic priming effect was significant, as evidenced by the significant main effect of prime relatedness ($F_1(1,58) = 55.39$, $p < .001$, $\eta^2 = .489$; $F_2(1,79) = 19.60$, $p < .001$, $\eta^2 = .199$), with faster RTs in the semantically related than semantically unrelated condition. There was no main effect of RP averaged over related and unrelated conditions ($F_1(1,58) = 0.58$, $p = .450$, $\eta^2 = .010$, but $F_2(1,79) = 14.87$, $p < .001$, $\eta^2 = .158$). Critically, RP interacted with prime relatedness ($F_1(1,58) = 5.81$, $p < .05$, $\eta^2 = .091$; $F_2(1,79) = 6.78$, $p < .05$, $\eta^2 = .079$), demonstrating an RP effect. Planned contrasts showed that the semantic priming effect in the high RP condition was significant ($F_1(1,30) = 31.64$, $p < .001$, $\eta^2 = .513$; $F_2(1,79) = 23.34$, $p < .001$, $\eta^2 = .228$), as was the smaller semantic priming effect found in the low RP condition ($F_1(1,28) = 33.03$, $p < .001$, $\eta^2 = .541$; $F_2(1,79) = 8.83$, $p < .01$, $\eta^2 = .100$).

Error rate. Overall, fewer errors were made in the semantically related than semantically unrelated condition ($F_1(1,58) = 9.60$, $p < .01$, $\eta^2 = .142$, but $F_2(1,79) = 2.74$, $p = .102$, $\eta^2 = .033$), demonstrating a semantic priming effect. The main effect of RP was non-significant ($F_1(1,58) = 0.44$, $p = .512$, $\eta^2 = .007$; $F_2(1,79) = 2.24$, $p = .138$, $\eta^2 = .028$), nor was the interaction between prime relatedness and RP (i.e., the RP effect) ($F_1(1,58) = 0.56$, $p = .457$, $\eta^2 = .010$; $F_2(1,79) = 1.25$, $p = .268$, $\eta^2 = .016$).

Quantiles. The correct RTs were analysed with QMPE (version 2.18) software developed by Cousineau, Brown, and Heathcote (2004), available at www.newcl.org/software/qmpe.htm. To calculate the quantiles estimates, which are variable-width histogram estimators, RTs were sorted from fastest to slowest and subsequently divided into five equal-sized bins (fastest 20%, next fastest 20%, etc.) for each participant and condition. The average RT of the last trial of the lower bin and the first trial of the higher bin, make up the four observed quantile estimates generated by QMPE. Only the fastest trial of the highest bin (containing the slowest RTs) is used to calculate the quantile estimate for the last quantile, therefore the slow outliers do not affect the quantile estimates and RT data were not be trimmed for outliers. The quantile estimates averaged over participants per condition are shown in Figure 1.

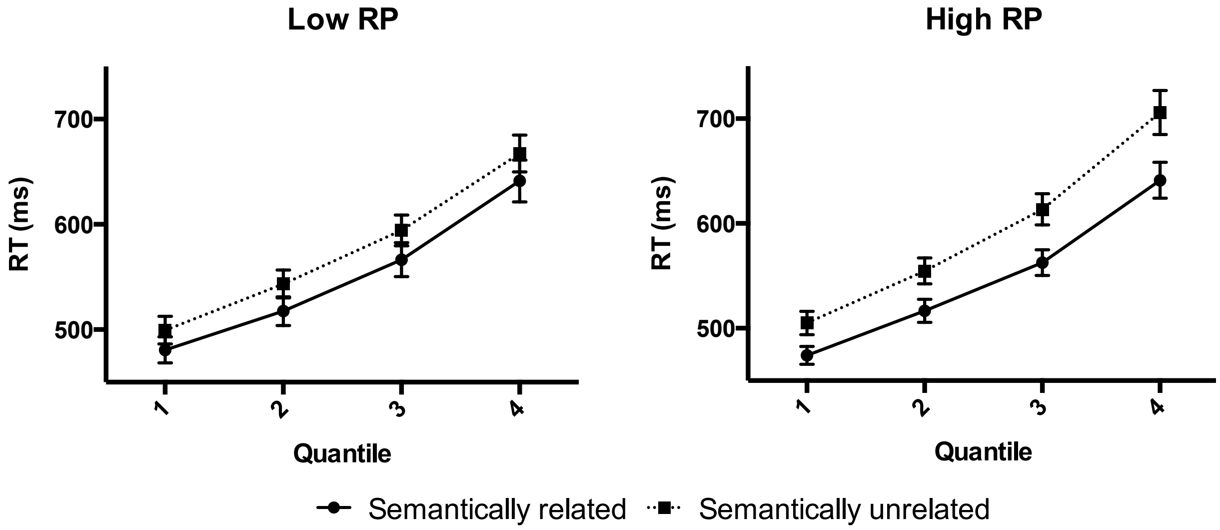

Figure 1. Lexical decision performance as a function of prime relatedness and quantiles in the low RP and high RP conditions. Error bars represent the standard error of the mean.

The quantiles were analysed using a 4 (quantile) x 2 (prime relatedness: related vs. unrelated) x 2 (RP: .25 vs. .75 related) factorial design, with quantile and prime relatedness as within-subject factors and RP as a between-group factor. The main effect of prime relatedness was significant ($F(1,58) = 82.15$, $p < .001$, $\eta^2 = .586$) as was the main effect of quantile ($F(3,174) = 564.62$, $p < .001$, $\eta^2 = .907$). Averaged over the high- and low-RP conditions, the semantic priming effect increased with quantile, as demonstrated by the significant quantile x prime relatedness interaction ($F(3,174) = 5.98$, $p < .01$, $\eta^2 = .094$). Critically, the three-way interaction of quantile, prime relatedness and RP was significant ($F(3,174) = 2.90$, $p < .05$, $\eta^2 = .048$). Planned contrast revealed that this interaction reflected different RT distribution patterns in the two RP conditions. In the high RP condition, the main effect of prime relatedness was significant ($F(1,30) = 46.24$, $p < .001$, $\eta^2 = .606$). The size of this semantic priming effect increased over quantiles, evidenced by the significant quantile x prime relatedness interaction ($F(3,90) = 6.73$, $p < .001$, $\eta^2 = .183$). In the low RP condition, the main effect of prime relatedness was also significant ($F(1,28) = 48.34$, $p < .001$, $\eta^2 = .633$). In contrast to the high RP condition, the size of the semantic priming effect remained constant across quantiles ($F(3,84) = 0.83$, $p = .482$, $\eta^2 = .029$).

Ex-Gaussian parameters. The estimates of Ex-Gaussian parameters are presented in Table 1. They were analysed as a 2 (prime relatedness: related vs. unrelated) by 2 (RP: low vs. high) factorial. For μ, the overall semantic priming effect was significant ($F(1,58) = 36.17$, $p < .001$, $\eta^2 = .384$), with faster RTs in the semantically related than the semantically unrelated condition. Of interest, RP did not modulate the semantic priming effect, as indicated by the non-significant interaction between prime relatedness and RP ($F(1,58) = 0.75$ $p = .391$, $\eta^2 = .013$). For σ, no significant main or interaction effects were found (all *F*s < 2.59, *ps* > .113). For τ, the main effect of prime relatedness was non-significant ($F(1,58) = 0.48$ $p = .492$, $\eta^2 = .008$). Critically, the interaction between prime relatedness and RP (“the RP effect”) was significant ($F(1,58) = 6.67$ $p < .05$, $\eta^2 = .103$). This was due to a significant effect of prime relatedness in the high RP condition ($F(1,30) = 4.94$ $p < .05$, $\eta^2 = .141$), but not in the low RP condition ($F(1,28) = 1.99$ $p = .169$, $\eta^2 = .066$).

In sum, replicating de Groot (1984), the analysis of mean RTs showed that in the lexical decision task with a short prime–target SOA, RP modulates the size of semantic priming effects. The RT distribution analysis showed that this modulation is not uniform across the quantiles, as indicated by the significant interaction between prime relatedness, RP and quantiles. As is apparent in the quantile plots, the increase in the semantic priming effect in the high RP condition is found only in the slower quantiles.

Consistent with this, the analysis of Ex-Gaussian parameters showed that the RP effect (an interaction between prime relatedness and RP) was found only with the τ parameter, and not with the μ parameter.

Task comparison

The present experiment, using the lexical decision task with a short prime–target SOA, showed that the RP effect was found only in the τ parameter: That is, the increase in the semantic priming effect in the high RP condition relative to the low RP condition increased across the quantiles. De Wit and Kinoshita (2014) had used the same critical stimuli and the same short prime–target SOA in a semantic categorization task (where participants were asked whether the target word denoted an animal or a nonanimal (man-made objects)) and found that the RP effect manifested itself as a shift in the RT distribution. That is, rather than increasing the size of semantic priming effect across the quantiles, the high RP magnified the semantic priming effect right from the earliest quantiles, and the increase remained constant across the quantiles. For ease of comparison between the tasks, we plotted the semantic priming effect (i.e., the difference between the semantically unrelated and semantically related prime conditions) as a function of quantile for the high- and low RP conditions in the two tasks. In these difference plots (also called delta plots), an overall shift of the RT distribution, with the size of the semantic priming effect constant across quantiles, is reflected as a flat line, an overadditive interaction of prime relatedness and quantile as a positively sloped line. The difference plots for both tasks are presented in Figure 2.

To examine the task-difference of the RP effect, the two experiments were combined and analysed with task (lexical decision vs. semantic categorization) as a factor. In the analysis of quantile estimates, the design was a four-way ANOVA with prime relatedness (related vs. unrelated), RP (.25 vs. .75 related), quantiles (1-4) and task (lexical decision vs. semantic categorization) as factors.

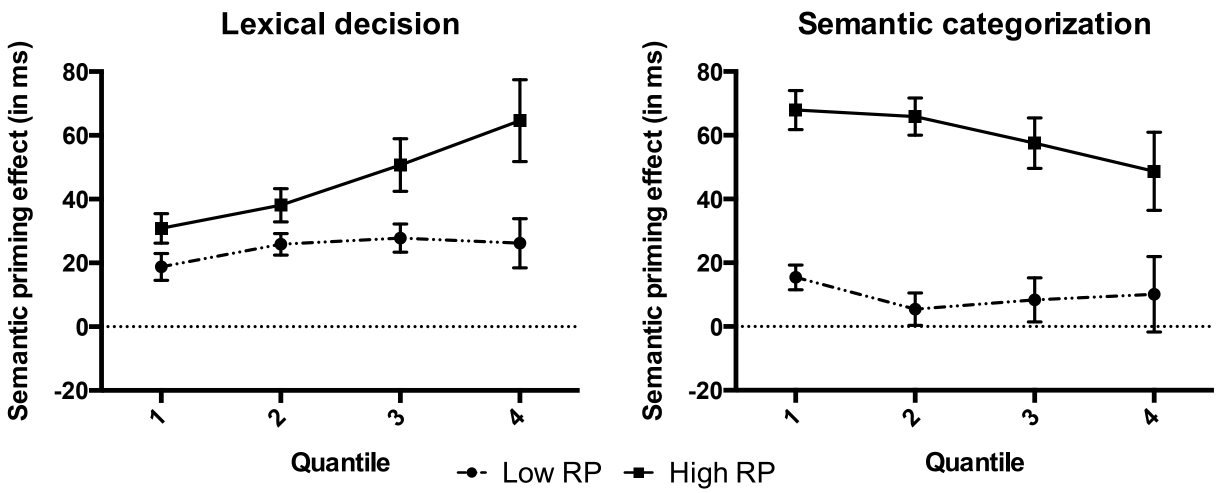

Figure 2. Semantic priming effects as a function of quantile for the lexical decision task and the semantic categorization task (De Wit & Kinoshita's Experiment 1 (2014). Error bars represent the standard error of the mean.

Quantile estimates. Averaged over quantiles, the RP effect was larger in the semantic categorization task compared to the lexical decision task as indicated by the significant task x prime relatedness x RP interaction ($F(1,116) = 5.85$, $p < .05$, $\eta^2 = .048$). Of greater interest, the four-way interaction between the factors prime relatedness, RP, quantile, and task was significant ($F(3,348) = 3.81$, $p < .05$, $\eta^2 = .032$) indicating that the RP manipulation affected different parts of the RT distribution patterns in the two tasks.

Ex-Gaussian parameters. We also examined the task difference in the RP effect in the analysis of the ex-Gaussian parameters. As the ex-Gaussian parameters for De Wit and Kinoshita's (2014, Experiment 1) semantic categorization study were not reported in that paper, they are presented, together with mean RTs, standard errors and error rates of that experiment in Table 2.

Table 2.

Summary of results for the semantic categorization task (De Wit & Kinoshita's Experiment 1, 2014), including the mean response latency (RT, in ms), standard errors (in parentheses), percentage error rate (%E), and ex-Gaussian parameters as a function of prime relatedness for both low and high relatedness proportion (RP) conditions as well as the 95% confidence intervals for the semantic priming effects and RP effect.

	RT (*SE*)	%E	μ	σ	τ
			Low RP		
Semantically related	594 (14.27)	4.9	488	63	101
Semantically unrelated	605 (16.02)	5.2	495	39	107
Priming effect	**11 ± 12.8**	**0.3 ± 2.1**	**7 ± 21.1**	**-24 ± 17.1****	**6 ± 27.4**
			High RP		
Semantically related	541 (11.39)	3.0	436	41	103
Semantically unrelated	599 (10.83)	9.3	505	39	93
Priming effect	**58 ± 15.2*****	**6.3 ± 2.7*****	**69 ± 20.8*****	**-2 ± 17.9**	**-10± 28.3**
RP effect	**47 ± 19.4*****	**6.0 ± 3.4****	**62 ± 29.0*****	**22 ± 24.2**	**-16± 38.6**

Note. RT = reaction time. RP effect refers to the semantic priming x RP interaction.
*** $p < .001$; ** $p < .01$.

For μ, the task x prime relatedness x RP interaction was highly significant ($F(1,116) = 16.08$, $p < .001$, $\eta^2 = .122$), indicating that the RP effect on the distributional shift was task-dependent. Recall that in the lexical decision task the RP effect (the interaction between prime relatedness and RP) was non-significant (F(1,58) = 0.75, p = .391, $\eta^2 = .013$). In contrast, in semantic categorization, the interaction between RP and prime relatedness was significant ($F(1,58) = 18.27$, $p < .001$, $\eta^2 = .240$). This was due to a significant effect of prime relatedness in the high RP condition ($F(1,29) = 45.72$, $p < .001$,

η^2 = .612), but not in the low RP condition (F(1,29) = 0.43, p = .516, η^2 = .015). For σ, the three-way interaction between prime related, RP and task was also significant (F(1,116) = 5.85, p < .05, η^2 = .048), with a larger RP effect in the semantic categorization than in the lexical decision task. For τ, the task x prime relatedness x RP interaction was significant (F(1,116) = 5.07, p < .05, η^2 = .042), again indicating task-dependence in the RP effect. In contrast to the μ parameter, here, the RP effect (i.e., the interaction between prime relatedness and RP) was present in the lexical decision task (F(1,58) = 6.67, p < .05, η^2 = .103) but not in the semantic categorization task (F(1,58) = 0.73, p = .398, η^2 = .012).

To summarize, the analysis of mean RT showed that RP effects are found in lexical decision (present experiment) at a short prime–target SOA, replicating a previous finding by De Groot (1984), as well as in semantic categorization as reported by De Wit and Kinoshita (2014, Experiment 1). Of greater interest, the RT distribution analyses showed that RP modulated the semantic priming effect differently in the two tasks. Specifically, in the semantic categorization task the RP effect reflected an overall distributional shift (an increase in the semantic priming effect in the high RP condition that was constant across the quantiles), as indicated by the significant RP effect in the μ parameter, but not in the τ parameter. The opposite pattern was found in the lexical decision task, with a significant RP effect in the τ parameter, but not in the μ parameter, indicating that the RP effect in this task increased across the quantiles.

General Discussion

The present study investigated the mechanism underlying the RP effect (modulation of semantic priming effect as a function of the proportion of related prime–target pairs) in the lexical decision task at a short (240 ms) prime–target SOA. Consistent with De Groot (1984), the analysis of mean RT showed a robust RP effect, with the semantic priming effect being larger in the high RP (.75 related) condition than in the low RP (.25 related) condition. The novel empirical contribution of the present study is to show that in the analysis of the RT distribution, the RP effect was reflected in the τ parameter, indicating that the increase in the semantic priming effect in the high RP condition was greater in the later quantiles. This pattern was in direct opposition to that found in semantic categorization (De Wit & Kinoshita, 2014, Experiment 1), which showed that the RP effect was found in the μ parameter, and not the τ parameter, indicating that the increase in semantic priming effect in the high RP condition was solely due to a distributional shift.

RT distribution analysis is useful in refining the putative mechanism underlying the semantic priming effect, by identifying the part(s) of the RT distribution affected by the manipulation (Pratte et al., 2010). We first discuss the extant views that have been proposed to explain the overadditive pattern of semantic priming effects on the RT distribution in the lexical decision task. We then turn to an account of the semantic priming effect in semantic categorization that we proposed recently, and contrast it with the lexical decision task. We conclude with a discussion of how the task difference in the RT distribution patterns can be explained by the different decision processes involved in the two tasks.

Semantic Priming Effect in Lexical Decision: Time-Based Explanation?

Recent studies investigating the basis of the semantic priming effect found at a short SOA in lexical decision have shown consistently that the semantic priming effect increases in later quantiles (i.e., the slower tail) of the RT distribution (Balota et al., 2008; Gomez et al., 2013; Hutchison et al., 2014). These later quantiles contain the target items that are responded to slowly. Balota et al. (2008) suggested that with an increased RT, the prime has more time to influence target processing; hence the semantic priming effect increases. Specifically, they tentatively suggested that “when SOA is short, there is insufficient time for the prime to be fully utilized before participants make their decision” (p.507). When the response to the target is slow, the prime–target SOA is effectively increased, and hence allows sufficient time for the prime to influence target processing.

This interpretation is consistent with the observation that with a long SOA (1250 ms), the semantic priming manipulation produced a distributional shift, indicating a prospective use of the prime (Balota et al., 2008, Experiment 5). It is of interest to note that Yap, Tse, and Balota (2009) found this distributional shift pattern was limited to individuals with high vocabulary knowledge, and the low-vocabulary knowledge individuals showed an overadditive pattern of semantic priming effect in the RT distribution. Similarly, Hutchison et al. (2014) reported that individual differences in attentional capacity qualify the type of strategies used, with only the high attentional capacity participants using the prospective strategy. It may be argued that this is consistent with the time-based explanation of the different patterns of semantic priming effects found with the short and long SOAs: Low vocabulary knowledge and low attentional capacity may be associated with less efficient processing of the prime, hence the prime–target SOA may be said to be effectively shorter for these individuals.

From this time-based perspective, the finding in the present experiment that the high RP magnified the semantic priming effect only for the targets in the later quantiles may reflect that it is only for these items for which there is sufficient time for the prime to influence target processing that the RP manipulation can modulate the semantic priming effect. However, it is clear that this time-based explanation would not work when applied to the semantic categorization data reported by De Wit and Kinoshita (2014). In that study, the prime–target SOA was also short, but the semantic priming effect reflected purely a distributional shift, and RP increased the amount of shift. The question arises as to what drives this task difference in the pattern of semantic priming effects, and hence the RP effects, on RT distributions. Specifically, why does the RP manipulation magnify the semantic priming effect in later quantiles in lexical decision, but does so right from the fastest responses in semantic categorization when the prime–target SOA is effectively very short? Given that exactly the same short prime–target SOA (240 ms) was used in the two studies, clearly, the idea that "when the prime–target SOA is short, there is insufficient time for the prime to be fully utilized" cannot explain why RP increased the semantic priming effect throughout the quantiles, from the fastest to the slowest, in semantic categorization. We suggest that the answer to the question lies in the different decision mechanisms involved in the two tasks, and how the semantic information of the prime is used, as we elaborate below.

Semantic Categorization vs. Lexical Decision: Different Decision Mechanisms

De Wit and Kinoshita (2014) proposed an account of semantic priming in the semantic categorization task framed in terms of evidence accumulation and source confusion, notions borrowed from the Bayesian Reader account of masked priming (Norris & Kinoshita, 2008) and the ROUSE (Responding Optimally to Unknown Sources of Evidence, Huber, Shiffrin, Lyle, & Ruys, 2001) model of short-term priming. The Bayesian Reader posits that in any task, evidence is accumulated for the task-specific hypothesis. In the case of semantic categorization, following the processing assumptions of the distributed models of semantic memory (e.g., Grondin, Lupker, & McRae, 2009; McRae & Boisvert, 1998; Smith, Shoben & Rips, 1974), De Wit and Kinoshita assumed that the evidence accumulated for the category decision consists of distributed semantic features (e.g., <flies>, <lays eggs>, etc.) that are diagnostic of the target's category membership. In line with the ROUSE model, De Wit and Kinoshita further assumed that the semantic features are accumulated not only from the target but also from the prime due to its close temporal and spatial proximity to the target. In other words, in a priming task, the source of the evidence is confused, and the semantic priming effect in semantic categorization represents a head-start in the evidence accumulation process: For targets preceded by related primes (e.g., *hawk–EAGLE; sofa–COUCH*), the semantic features of the prime are similar to the target and hence the prime contributes evidence consistent with the decision to the target; for targets preceded by unrelated primes (e.g., *cart–EAGLE; hyena–COUCH*), the features contributed by the prime are inconsistent with the decision required to the target. It is this head-start in the evidence accumulation process that is reflected in the distributional shift pattern of semantic priming in this task.

In contrast, in the lexical decision task, the decision required is whether the target is a word or a nonword, a decision that need not be purely semantically driven. While some (e.g., Plaut, 1997) have suggested that this discrimination may be based on semantic information, this has been challenged by studies showing that patients with severe semantic deficits can make lexical decisions without comprehending the word's meaning (e.g., Blazely, Coltheart & Casey, 2005; Bormann & Weiller, 2012). In the non-patient population also, current computational models of word recognition (e.g., Davis, 2010; Norris, 2006; Norris & Kinoshita, 2012) assume that orthographic information is the main source of information used in making a lexical decision, and these models can account for a large proportion of item-based variance in large-scale databases of lexical decision like the English Lexicon Project (ELP, Balota et al., 2007). From this perspective, while we are not denying the role of semantics, it is not the only source (as has been assumed in Plaut's (1997) implementation of lexical decision in his Simulation 2), but just one of the multiple sources of information used in discriminating between words and nonwords.

When all nonword targets are preceded by a semantically unrelated prime, as is typical and as in the present lexical decision experiment, the relatedness of prime and target (or lack thereof) is a useful cue to the target's lexical status, as only word targets are related to primes. This relatedness information is used *retrospectively* as the assessment of relatedness is possible only after the target is presented (e.g., Neely & Keefe, 1989; Neely, Keefe & Ross, 1989). However, as we argued above, this semantic relatedness information need not be the only source of information used to make a word–nonword decision[4]—note that otherwise word targets preceded by a semantically unrelated prime would be wrongly classified as a nonword. What we are suggesting then is that the retrospective assessment of prime–target relatedness is used as one of the cues to form a "compound cue" (Ratcliff & McKoon, 1988) to drive the word–nonword discrimination. Compound cues are time-evolving sets of features that contain orthographic, phonological, and semantic information, whose strength represents the rate of evidence accumulation (the drift rate in the diffusion model, Ratcliff, 1978). As noted by Pratte et al. (2010), in evidence accumulation models, an increase in the strength of evidence produces the overadditive pattern in RT distribution. Gomez et al. (2013) similarly noted that the overadditive pattern of semantic priming effect they found in the RT distribution of lexical decision naturally falls out of the compound cue model of semantic priming, citing Ratcliff and McKoon (1988).

On the assumption that RP affects the extent to which the prime is useful in making the decision required to the target, the different RT distribution patterns of RP effects in the lexical decision and semantic categorization tasks follow naturally from the fact that the processes underlying semantic priming effects in the two tasks are different, as described above. In semantic categorization, De Wit and Kinoshita (2014) found that the semantic priming effect was reflected in a distributional shift, and that the

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[4] Balota et al. (2008) have made a similar point that lexical decision may involve both "the influence of the prime", and "the word recognition processes that drive lexical decisions for the target in the unrelated condition" (p.507). However, their suggestion was that there is a "race" between these sources of information; in contrast, our view, as elaborated below, is that they are combined to form a "compound cue".

increase in the size of semantic priming effect due to the RP manipulation was constant throughout the quantiles, starting from the fastest quantile onwards. In semantic categorization, the decision required is whether the target is an animal or not. This decision is based directly on the semantic features that are diagnostic of the word denoting animacy (e.g., <lays eggs>, <flies>). A high RP in this task means that on a high proportion of trials the semantic features contributed by the prime are similar to those of the target, hence it is beneficial to combine the semantic features accumulated from the prime with that of the target (there is more source confusion), resulting in a larger semantic priming effect reflected in the distributional shift.

In contrast, in lexical decision, the decision required is whether the target is a word or a nonword. Here, it is not the semantic features of the prime per se but rather the relatedness between the prime and target that is diagnostic of the target's lexical status, and the prime diagnosticity increases with the nonword ratio. As Neely at al. (1989) pointed out, an increase in the nonword ratio (the proportion of nonword targets given an unrelated prime) goes hand in hand with an increase in RP. As RP, and hence nonword ratio increases, the presence/absence of a semantic relationship between prime and target becomes an increasingly useful indicator of the target's lexical status. Thus the increase in nonword ratio (which is almost always correlated with the RP) may be regarded as increasing the strength of evidence (or the rate of evidence accumulation) for the word–nonword discrimination, and hence the RP effect (actually the nonword ratio effect) is found in the τ parameter, reflecting the increase in overadditivity in RT distribution.

Conclusion

Contrary to the widely held assumption that semantic priming effects obtained at a short prime–target SOA are automatic, RP effects are found with a short prime–target

SOA in lexical decision. Through the analysis of the RT distribution, the present study showed that the RP effect reflects a greater reliance on the retrospective semantic matching strategy in the high RP condition, manifested as an increase in the semantic priming effect in the slow tail of the RT distribution. This pattern contrasts with that found in the semantic categorization task in which the semantic priming effect is manifested as a shift in the RT distribution representing source confusion (integration of evidence contributed by the prime with that accumulated from the target), and RP magnifies the amount of distributional shift. Thus, although RP effects are found in both tasks, task dissociation is revealed via RT distribution analyses, reminding us of the usefulness of "moving beyond the mean" (Balota & Yap, 2011). The task dissociation revealed in the RT distribution analyses indicates that the modulation of semantic priming effects depends on the task-specific decision processes (cf. Norris, 2006; Norris & Kinoshita, 2008).

References

Antos, S. J. (1979). Processing facilitation in a lexical decision task. *Journal of Experimental Psychology, 5*, 527-545.

Balota, D. A., & Yap, M. J. (2011). Moving beyond the mean in studies of mental chronometry: The power of response time distributional analyses. *Current directions in psychological science, 20*, 160-166.

Balota, D. A., Yap, M. J., Cortese, M. J., & Watson, J. M. (2008). Beyond mean response latency: Response time distributional analysis of semantic priming. *Journal of Memory and Language, 59*, 495-523.

Balota, D. A., Yap, M. J., Cortese, M. J., Hutchison, K. A., Kessler, B., Loftis, B., Neely, J. H., Nelson, D. L., Simpson, G. B., & Treiman, R. (2007). The English Lexicon Project. *Behavior Research Methods, 39*, 445-459.

Becker, C. A. (1980). Semantic context effects in visual word recognition: An analysis of semantic strategies. *Memory & Cognition, 8*, 493-512.

Blazely A. M, Coltheart M, & Casey, B. J. (2005). Semantic impairment with and without surface dyslexia: Implications for models of reading. *Cognitive Neuropsychology, 22,* 695-717.

Bormann, T., & Weiller, C. (2012). "Are there lexicons"? A study of lexical and semantic processing in word-meaning deafness suggests "yes". *Cortex, 48*, 294-307.

Brysbaert, M., & New, B. (2009). Moving beyond Kuçera and Francis: A critical evaluation of current word frequency norms and the introduction of a new and improved word frequency measure for American English. *Behavior Research Methods, 41*, 977-990.

Cousineau, D., Brown, S. [D.], & Heathcote, A. (2004). Fitting distributions using maximum likelihood: Methods and packages. *Behavior Research Methods, Instruments, & Computers,* 36, 742-756.

Davis, C. J. (2010). The spatial coding model of visual word identification. *Psychological Review, 117*, 713-758.

De Groot, A. M. B. (1984). Primed lexical decision: Combined effects of the proportion of related prime–target pairs and the stimulus-onset asynchrony of prime and target. *The Quarterly Journal of Experimental Psychology Section A, 36*, 253-280.

De Wit, B., & Kinoshita, S. (2014, February 24). Relatedness proportion effects in semantic categorization: Reconsidering the automatic spreading activation process. *Journal of Experiment Psychology: Learning, Memory, and Cognition.* Advance online publication. doi: 10.1037/xlm0000004

Forster, K. I., & Forster, J. C. (2003). DMDX: A windows display program with millisecond accuracy. *Behavior Research Methods, Instruments, and Computers, 35*, 116-124.

Gomez, P., Perea, M., & Ratcliff, R. (2013). A diffusion model account of masked vs. unmasked priming: Are they qualitatively different? *Journal of Experimental Psychology: Human Perception and Performance*, *39,* 1731-1740.

Grondin, R., Lupker, S. J., & McRae, K. (2009). Shared features dominate semantic richness effects for concrete concepts. *Journal of Memory and Language, 60*, 1019.

Heathcote, A., Popiel, S. J., & Mewhort, D. J. K. (1991). Analysis of response time distributions: An example using the Stroop task. *Psychological Bulletin, 109*, 340-347.

Hohle, R. H. (1965). Inferred components of reaction times as functions of foreperiod duration. *Journal of Experimental Psychology, 69*, 382-386.

Huber, D. E., Shiffrin, R. M., Lyle, K. B., & Ruys, K. I. (2001). Perception and preference in short-term word priming. *Psychological Review, 108*, 149-182.

Hutchison, K. A. (2007). Attentional control and the relatedness proportion effect in semantic priming. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 33*, 645-662.

Hutchison, K. A., Heap, S. J., Neely, J. H., & Thomas, M. A. (2014). Attentional control and asymmetric associative priming. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 40*, 844-856.

Hutchison, K. A., Neely, J.H., & Johnson, J.D. (2001). With great expectations, can two "wrongs" prime a "right"?. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 27*, 1451-1463.

Kahan, T. A., Neely, J. H., & Forsythe, W. (1999). Dissociated backward priming effects in lexical decision and pronunciation tasks. *Psychonomic Bulletin & Review, 6*, 105-110.

Landauer, T. K., McNamara, D. S., Dennis, S., & Kintsch, W. (2007). *Handbook of Latent Semantic Analysis.* Mahwah, NJ: Lawrence Erlbaum Associates, Publishers.

McRae, K., & Boisvert, S. (1998). Automatic semantic similarity priming. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 24,* 558-572.

McRae, K., Cree, G., Seidenberg, M., & McNorgan, C. (2005). Semantic feature production norms for a large set of living and nonliving things. *Behavior Research Methods, 37*, 547-559.

Neely, J. H. (1977). Semantic priming and retrieval from lexical memory: Roles of inhibitionless spreading activation and limited-capacity attention. *Journal of Experimental Psychology: General, 106*, 226-254.

Neely, J. H. (1991). Semantic priming effects in visual word recognition: A selective review of current findings and theories. In D. Besner & G.W. Humphreys (Eds.), *Basic processes in reading: Visual word recognition* (pp. 264-336). Hillsdale, NJ: Erlbaum.

Neely, J. H., & Keefe, D. E. (1989). Semantic context effects on visual word processing: A hybrid prospective/retrospective processing theory. In G.H. Bower (Ed.). *The* *psychology of learning and motivation: Advances in research and theory* (Vol. 24, pp. 207-248). New York, NY: Academic Press.

Neely, J. H., Keefe, D. E., & Ross, K. L. (1989). Semantic priming in the lexical decision task: Roles of prospective prime-generated expectancies and retrospective semantic matching. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 15*, 1003-1019.

Norris, D. (1984). The mispriming effect: Evidence for an orthographic check in the lexical decision task. *Memory & Cognition, 12*, 470-476.

Norris, D. (2006). The Bayesian Reader: Explaining word recognition as an optimal Bayesian process. *Psychological Review, 113*, 327-357.

Norris, D., & Kinoshita, S. (2008). Perception as evidence accumulation and Bayesian inference: Insights from masked priming. *Journal of Experimental Psychology: General, 137*, 434-455.

Norris, D., & Kinoshita, S. (2012). Reading through a noisy channel: Why there's nothing special about the perception of orthography. *Psychological Review, 119*, 517-545.

O'Connor, R. E., & Forster, K. I. (1981). Criterion bias and search sequence bias in word recognition. *Memory & Cognition, 9*, 78-92.

Plaut, D. C. (1997). Structure and function in the lexical system: Insights from distributed models of word reading and lexical decision. *Language and Cognitive Processes, 12*, 765-805.

Posner, M. I., & Snyder, C. R. R. (1975). Attention and cognitive control. In R.L. Solso (Ed.), *Information processing and cognition: The Loyala symposium* (pp. 55-85). Hillsdale, NJ: Lawrence Erlbaum Associates, Inc.

Pratte, M. S., Rouder, J. N., Morey, R. D., & Feng, C. (2010). Exploring the differences in distributional properties between Stroop and Simon effects using delta plots. *Attention, Perception, & Psychophysics, 72*, 2013-2025.

Ratcliff, R. (1978). A theory of memory retrieval. *Psychological Review, 88*, 552-572.

Ratcliff, R., & McKoon, G. (1988). A retrieval theory of priming in memory. *Psychological Review, 95*, 385-408.

Seidenberg, M. S., Waters, G. S., Sanders, M., & Langer, P. (1984). Pre- and postlexical loci of contextual effects on word recognition. *Memory & Cognition, 12*, 315-328.

Smith,E. E., Shoben, E. J., & Rips, L. J. (1974). Structure and process in semantic memory: A featural model of semantic decisions. *Psychological Review, 81*, 214-241.

Thomas, M. A., Neely, J. H. & O'Connor, P. (2012). When word identification gets tough, retrospective processing comes to the rescue. *Journal of Memory and Language, 66*, 623-643.

Tweedy, J., Lapinski, R., & Schvaneveldt, R. (1977). Semantic-context effects on word recognition: Influence of varying the proportion of items presented in an appropriate context. *Memory & Cognition, 5*, 84-89.

Yap, M. J., Balota, D. A., & Tan, S. E. (2013). Isolating lexical and decision processes in the lexical decision task. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 39*, 140-158.

Yap, M. J., Tse, C.-S., & Balota, D. A. (2009). Individual differences in the joint effects of semantic priming and word frequency revealed by RT distributional analyses: The role of lexical integrity. *Journal of Memory and Language, 61*, 303-325.

Chapter 4—The Masked Semantic Priming Effect is Task-Dependent: Reconsidering the Automatic Spreading Activation Process

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The Masked Semantic Priming Effect is Task-Dependent: Reconsidering the Automatic Spreading Activation Process

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Abstract

Semantic priming effects are popularly explained in terms of an automatic spreading activation process, according to which the activation of a node in a semantic network spreads automatically to interconnected nodes, pre-activating a semantically related word. It is expected from this account that semantic priming effects should be routinely observed when the prime identity is veiled from conscious awareness, but the extant literature on masked semantic priming effects is notoriously mixed. In the present study, we use the same prime–target pairs in the lexical decision task and semantic categorization task and show that while masking the prime eliminates the semantic priming effect in lexical decision, reliable semantic priming effects are observed with both masked and unmasked primes in the semantic categorization task. We explain this task-dependence in terms of our account of semantic priming effects based on the notions of evidence accumulation and source confusion (De Wit & Kinoshita, 2014a; 2014b), and support our account by means of RT distribution analyses.

Keywords: semantic priming; masked priming; visual word recognition; semantic categorization

Introduction

In visual word recognition, the notion of *automatic spreading activation* plays a key role in explaining the semantic priming effect, the finding that response to a word is facilitated when it is preceded by a semantically related word relative to an unrelated word (Meyer & Schvaneveldt, 1971, see McNamara, 2005; Neely, 1991, for reviews). According to this notion, word meanings are represented as interconnected nodes within a semantic/lexical network, and reading a word activates its corresponding node in the network, with the activation spreading automatically to close, semantically related representations. Hence when the to-be-processed word (the target) is presented shortly after a semantically related prime, the activation level of the target word would be higher than when the preceding word was semantically unrelated, facilitating its recognition (Collins & Loftus, 1975; Neely, 1977; Posner & Snyder, 1975). An alternative framework, based on the notion of distributed representations (e.g., Masson, 1995; McRae, de Sa & Seidenberg, 1997; Plaut & Booth, 2000; Smith, Shoben & Rips, 1974) dispenses with the notion of unitized nodes, and concepts are instead represented as a set of distributed semantic features (e.g., <has a tail>, <has legs>, <moos>). We will discuss the semantic priming effect within the distributed framework in more detail later, and for now, focus on the account of the semantic priming effect based on the notion of spreading activation within a semantic network.

The present paper reconsiders the automatic spreading activation process as an explanation of semantic priming effects.[1] An automatic process is generally assumed to have the following characteristics: 1) is fast-acting, 2) is capacity-free, 3) can occur without intention, 4) is involuntary or uncontrollable, and 5) can occur without

[1] The automaticity of semantic activation has been challenged previously based on studies using the Stroop task, and semantic priming studies in which the nature of the task performed on the prime is manipulated. Readers are referred to Neely and Kahan (2001) for discussion of this literature.

conscious awareness (e.g., Neely & Kahan, 2001; Posner & Snyder, 1975). In line with these criteria, semantic priming effects observed with a short prime–target SOA (less than 250 ms) are generally assumed to be driven by an automatic spreading activation process (Neely, 1977; see Hutchison, 2007, for a review). Contrary to this assumption, however, we recently reported that the size of semantic priming effects in the semantic categorization task and the lexical decision task at a short prime–target SOA (240 ms) was modulated by the proportion of related trials, which indicates that the spread of semantic activation is not "uncontrollable" (De Wit & Kinoshita, 2014a; 2014b). In addition, we found that the RT distribution pattern underlying the semantic priming effects in the semantic categorization task differed from that in the lexical decision task, suggesting that the mechanism responsible for the semantic priming effects is task-dependent. This task-dependence is at odds with the automatic spreading activation process, which "should not be modulated by differing task demands." (p. 298, Neely, 1991). Based on these results, we (De Wit & Kinoshita, 2014a; 2014b) have argued that the automatic spreading activation process does not explain semantic priming effects obtained with short prime–target SOAs, and that the effects are instead better explained by an alternative account, based on the notion of evidence accumulation and source confusion (to be explained in detail later).

In the present paper, we build on our previous works and present another challenge for the automatic spreading activation account, this time based on the criterion that automatic processes can occur "without conscious awareness". In the context of semantic priming, this means that semantic priming effects should be obtained when the prime is presented very briefly and backward-masked so that it is not consciously identified. In line with this, in reviewing the semantic priming literature, Neely (1991) noted that the finding of subliminal priming effects is "one of the strongest pieces of evidence supporting an automatic spreading activation account" (p. 297).

However, as we summarize below, the empirical literature on masked semantic priming effect to date has been contentious to say the least (see Holender, 1986; Kouider & Dehaene, 2007; McNamara, 2005 for reviews).

Holender's (1986) review of the subliminal perception literature pointed out that many of the earlier studies claiming to have found masked semantic priming effects (e.g., Marcel, 1983) had methodological shortcomings, such as stimulus confounds, and failed to be replicated (Fowler, Wolford, Slade, & Tassinary, 1981). These earlier studies relied solely on the brief presentation of the prime and a backward mask to prevent the prime from being consciously identified, which was not always successful. Subsequent studies adopted the "three-field" procedure developed by Forster and Davis (1984) in which a briefly presented prime is preceded by a forward mask (typically a series of #s) and is backward-masked by the target. The use of a forward mask as well as a backward mask makes the prime onset more difficult to detect, and seems to be more successful in preventing conscious recognition of the prime's identity. Studies using the three-field procedure showed that reliable masked priming effects can be obtained in visual word recognition tasks (most commonly the lexical decision task) for orthographic, phonological, and morphological relationships (see Kinoshita & Lupker, 2003, for a survey of this literature), but that masked semantic priming effects are typically weak and unreliable (e.g., Perea & Gotor, 1997; Rastle, Davis, Marslen-Wilson & Tyler, 2000).

More recently, Dehaene and colleagues (1998) used number stimuli in a magnitude judgment task ("Is the number bigger than 5?") and reported that category-congruent primes facilitated the response to targets relative to category-incongruent primes (the *category congruity effect*, e.g., response to 3 was faster when it was primed by 1 than 6). Kouider and Dehaene (2007) reviewed this and subsequent studies investigating the category congruity effect, and concluded that "some researchers still debate the semantic interpretation of these experiments" (p.863). Specifically, these studies used small categories that contain a finite set of exemplars, and it is unclear whether the observed masked congruity effect reflected learned stimulus-response mapping or semantic processing (see, e.g., Damian, 2001). Also, the repeated use of a small finite set of stimuli contrasts with a typical word recognition experiment in which a target is presented only once.

However, there are studies not mentioned in Kouider and Dehaene's review that presented the word targets only once and reported finding reliable category congruity effects (e.g., Bueno & Frenck-Mestre, 2002; 2008; Frenck-Mestre & Bueno, 1999; Quinn & Kinoshita, 2008). We will discuss later in greater depth the boundary conditions for finding masked semantic priming effects in semantic categorization, and for now note that unlike the ubiquitous finding of semantic priming effects with visible primes, findings of semantic priming effect with masked primes have been mixed. This then is the question we pose: Why is the masked semantic priming effect so elusive, if, as is widely assumed, semantic priming effects are driven by an automatic spreading activation process?

We will argue that the automatic spreading activation process does not have adequate explanatory power to predict when semantic priming effects can be found with masked primes, and that an alternative account is needed. To this end, our paper will be organized as follows. We first review the literature of semantic priming effects observed with visible primes presented at a short prime–target SOA using the lexical decision task and make the case that these effects are better explained by the retrospective semantic matching strategy than by the automatic spreading activation process. We then present Experiment 1, using the lexical decision task, to test this view. Specifically, we will show that in this task, contrary to what is expected from automatic spreading activation, but as expected from retrospective semantic matching, the semantic priming effect found with visible (unmasked) primes is eliminated when the prime is masked.

In the second half of the paper, we turn to the semantic categorization task. We first review the literature and identify the boundary conditions for finding reliable masked semantic priming effects. We will then discuss these conditions within our theory of semantic priming based on the notions of evidence accumulation and source confusion. We put our theory to a test in Experiment 2, using the same prime–target pairs used in Experiment 1 in a semantic categorization task, and show that in this task, reliable semantic priming effects are found with masked primes as well as unmasked primes. In both experiments, we will back up our claims concerning the mechanisms responsible for the semantic priming effects in the lexical decision and semantic categorization tasks with the analysis of the RT distribution.

To begin with, we present a review of the literature to provide a rationale for our prediction that masking the prime should eliminate semantic priming effects in the lexical decision task.

Semantic Priming in the Lexical Decision Task

The lexical decision (word–nonword discrimination) task is arguably the most popular task used to study semantic priming. When visible primes are used, robust semantic priming effects are found in this task, even when the prime–target SOA is short (e.g., Neely, 1976, 1977; McRae & Boisvert, 1998). These effects have been taken as a marker of automatic semantic activation, on the assumption that a short SOA does not allow enough time to generate expectancies about the identity of the upcoming target from the prime, that is, it precludes strategic prospective use of the prime. It is important to note however, that the short SOA does not preclude strategic *retrospective* use of the prime, a process referred to as retrospective semantic matching (Neely, 1991), or post-access coherence checking (De Groot, 1983; 1984).

According to this strategy, after the target is presented but before the decision to the target is made, the meaning of the target is matched to that of the prime. In the lexical decision task, a target may be a word or a nonword, but only the word targets are semantically related to a word prime. This is the case as experimenters typically avoid pairing nonword targets with word primes that are semantically related to a word that the nonword resembles (e.g., *aunt–UMCLE; father–MOHTER*). Semantic relatedness of prime and target is thus a viable indicator of the target's lexical status: If a semantic relationship between prime and target can be found, the target would be a word, if not, the target is more likely to be a nonword. Support for this strategy can be found in the fact that the size of semantic priming effect in lexical decision varies as a function of "nonword ratio"—the proportion of nonword targets given a target is semantically unrelated to the prime (Neely, Keefe & Ross, 1989): The higher the nonword ratio, the more diagnostic the absence of semantic relationship is to the target's nonword status. A typical lexical decision experiment contains an equal number of word and nonword targets, and an equal number of semantically related word targets and semantically unrelated word targets: This corresponds to a nonword ratio of .67 (= 100/(100 + 50)), thus providing a condition conductive to the retrospective semantic matching strategy.

Note that the prime–target relatedness is assessed after the target is presented, i.e., it is retrospective. Hence a short prime–target SOA should not preclude this strategy, and it may explain the semantic priming effect observed in lexical decision with a short prime–target SOA.

RT Distribution Analysis: Identifying the Retrospective Semantic Matching Process

The view that semantic priming effects at short SOAs obtained with the lexical decision task are due to the use of a retrospective rather than prospective use of the prime has received much support from recent studies that analysed the RT distribution, rather than rely on mean RT alone (e.g., Balota, Yap, Cortese, & Watson, 2008; Gomez, Perea, & Ratcliff, 2013; Thomas, Neely, & O'Connor, 2012; Yap, Balota, & Tan, 2013).

As Balota and Yap (2011) pointed out, when the influence of a manipulation on performance is examined, moving beyond the mean "affords significant advances over analyses of means" (p.165). Most RT distributions are positively skewed and by focussing on the mean RT alone effects of experimental manipulations on the different parts of the RT distribution can be missed. An experimental manipulation can result in the same mean RT effects, but actually produce different RT distribution patterns. For example, the manipulation can affect the whole RT distribution, or only the skew of the RT distribution, or both. One method for visualising these different effects is quantile plots. In this method, for each participant and each condition, RT data are organised from fastest to slowest, and then divided into equal-sized portions (RT bins), called quantiles, that contain for example to fastest 25% of RTs, the next fastest 25%, and so on. The average of the last trial of the faster quantile and the first trial of the slower quantile make up the quantile estimate. The quantile estimates are then plotted separately for different conditions. In semantic priming studies, two distributions are plotted; one for the semantically related and one for the semantically unrelated condition, and the difference between the two distributions reflects the semantic priming effect. This difference can be constant throughout the quantiles, showing shift of the whole RT distribution, or increase or decrease throughout the quantiles, showing an effect of the experimental manipulation on the skew of the RT distribution.

In the lexical decision task, when a short SOA is used, the semantic priming effect increases across the quantiles (Balota et al., 2008, Experiment 2 and 3; Gomez et al., 2013). Balota et al. suggested that this overadditive interaction between quantiles and semantic priming reflects a retrospective prime retrieval process. Thomas et al. (2012) provided direct evidence for this view. In their lexical decision study, they manipulated the direction of prime–target association to isolate retrospective processes from prospective processes like automatic spreading activation and expectancy generation. In prime–target pairs that have a forward association only (e.g., *keg*–*BEER*), only prospective mechanisms can produce priming effects, whereas priming effects obtained with prime–target pairs with backward association only (e.g., *small*–*SHRINK*) are solely attributable to retrospective processes (e.g., Kahan, Neely, & Forsyth, 1999). Thomas et al. (2012) found that the size of the semantic priming effect increased across quantiles only when the prime–target pairs had a backward association, that is, symmetric and backward association pairs. This finding provided support for the view that the overadditive interaction between prime relatedness and quantile reflects the use of the retrospective semantic matching strategy (see Hutchison, Heap, Neely, & Thomas, 2014 for a similar conclusion).

Masked Semantic Priming and the Retrospective Semantic Matching Process

The idea that semantic priming in the lexical decision task with a short prime–target SOA is driven not by automatic spreading activation, but by retrospective semantic matching, could explain why the finding of the semantic priming effect with masked primes is elusive in this task. Backward-masking of the prime prevents the conscious identification of the prime, and subjects are often unaware even of its presence. This would also prevent the assessment of the relationship between the target and the prime, that is, it precludes the retrospective semantic matching strategy. As

Neely (1991) stated, why would a participant "try to adopt a strategy of finding a semantic relation between the target and an event, i.e., the masked prime, which the subject claims does not even exist" (p.317).

Support for the idea that backward-masking of the prime prevents use of the retrospective semantic matching strategy has been reported by De Groot (1983). She used "mediated prime–target pairs", where the prime and target are related indirectly, mediated by an intervening word that is related to each word (e.g., *lion – (tiger) – stripes*). At a short (240 ms) SOA, these mediated pairs produced priming relative to unrelated controls, but when the prime was backward-masked, no mediated priming effect was found. De Groot took the results as indicating that the retrospective semantic matching strategy (what she called post-access coherence checking) was responsible for the mediated priming effect observed with visible primes, and that masking the prime precluded this strategy.

Experiment 1

To summarize the literature reviewed above, the semantic priming effect observed in lexical decision with a short prime–target SOA, is most likely produced by the retrospective semantic matching strategy rather than the automatic spreading activation process, and this strategy is identified with an increasing semantic priming effect across quantiles in a RT distribution. Backward-masking the prime would prevent the retrospective assessment of the prime–target relationship, and this would explain why masked semantic priming effects have been elusive with this task. Experiment 1 tested this view. Specifically, we expected that: 1) with an unmasked prime presented at a short prime–target SOA, semantic priming effect would be found; 2) this effect is produced by the retrospective semantic matching strategy and therefore the RT distribution should show an overadditive interaction between prime relatedness and quantiles, 3) under the assumption that awareness of the prime's identity is a prerequisite for the retrospective semantic matching strategy, masking the prime would eliminate the semantic priming effect.

Method

Participants. Sixty undergraduate students of Macquarie University, 47 women and 13 men (M_{age} = 22.0 years) participated in Experiment 1, in return for course credit. All participants had normal or corrected-to-normal vision. Of those, data from one participant was excluded because of a high (over 20%) error rate.

Design. The experiment used a 2 (prime relatedness: semantically related vs. semantically unrelated) x 2 (mask: masked vs. unmasked) factorial design, with prime relatedness manipulated within subjects and mask between groups. The dependent variables were RT and error rate.

Stimuli. A lexical decision task was used. Eighty critical word targets were used, which consisted of 40 animal and 40 nonanimal (man-made items) exemplars. The word targets were on average 6.5 letters long (range 3–10) and had an average Log Subtitle Contextual Diversity value (LgSUBTLCD) of 2.16 (LgSUBTLCD is the Log of the SUBTLEX contextual diversity value, corresponding to the percentages of films containing the word, and is argued by Brysbaert & New (2009) to be the best predictor of lexical decision latency. It is highly correlated with Log word frequency). The animal and nonanimal exemplar targets were matched on frequency and length; animal targets were on average 6.6 letters long and had an average LgSUBTLCD value of 1.95, nonanimal targets were on average 6.4 letters long with an average LgSUBTLCD of 2.35.

Each word target was paired with two primes; a semantically-related prime (e.g., *hawk–EAGLE; sofa–COUCH*) and a semantically unrelated, category-incongruent prime (e.g., *cart–EAGLE; hyena–COUCH*). The related primes were selected on the basis of high semantic similarity according to the McRae, Cree, Seidenberg, and McNorgan's (2005) semantic feature production norms. The selection criterion was dictated by the fact that the same prime–target pairs were used as the critical stimuli in the semantic categorization task in Experiment 2, and the theoretical basis for this selection criterion will be explained later, under "The importance of semantic feature overlap". For now, suffice it to point out that semantic priming effects in the lexical decision task are observed with a variety of semantic relationships, including this type of relationship (cf. McRae & Boisvert, 1998). McRae et al.'s (2005) norms include 541 concepts (of living- and nonliving things), with 2,526 features, and similarity between two concepts is represented by the cosine, "the dot product between two concept vectors, divided by the product of their lengths" (p.553). Cosine ranges from -1 (opposite vectors) to 1 (identical vectors), with 0 indicating independent vectors. Based on these cosines, the average similarity for the word targets was .63. Again, the average similarity was matched for animal and nonanimal exemplar targets, with an average similarity of .64 for the animal targets and .62 for the nonanimal targets. Primes and targets were re-paired to create the semantically unrelated condition. Primes never occurred as targets. The critical word targets were divided into two sets, matched on mean length, frequency, and similarity. The assignment of lists to the prime conditions was counterbalanced so that each prime and target occurred once as a related pair and once as an unrelated pair across the two lists.

Eighty nonword targets were selected from the English Lexicon Project (ELP) Database (Balota, Yap, Cortese, Hutchison, Kessler, Loftis, et al., 2007, available at http://elexicon.wustl.edu/) to match the critical word targets on length and orthographic neighbourhood size. The nonword targets had an average accuracy of .80 or higher, in the ELP Database. Each nonword target was paired with a word prime. To ensure neither animalness nor prime-length was an indicator of the target's word status, half of the nonword targets were preceded by an animal prime and prime-length for nonword targets was statistically matched ($t(158) = 0.24$, $p = .814$) to that of the critical word targets.

Additionally, 160 filler trials were used, of which half consisted of word targets and half nonword targets. Of the 80 word targets, half were paired with a related prime and the other half paired with an unrelated prime. Because not all animal words appeared in the McRae et al. norms, the average relatedness for the filler items was verified using the Latent Semantic Analysis norms (LSA, Landauer, McNamara, Dennis, & Kintsch, 2007). According to these norms, the average relatedness of the word filler trials was .47. The 80 filler nonword targets also had an average accuracy of .80 or higher, were paired with word primes and matched on length to the filler word targets ($t = -1.546$, $p = .124$). In this lexical decision experiment, the overall relatedness proportion was 50% and the nonword ratio .67.

The word pairs in the practice phase were comparable to the critical target items used in the test phase. There were 16 practice trials and the first two trials of each block were warm-up trials. Neither the practice nor warm-up trials were included in the analysis.

Apparatus and procedure. Participants were tested individually or in pairs. The Windows-based DMDX display system (version 4.0.6.0) developed by Forster and Forster (2003) was used for stimulus presentation and data collection. The stimuli were presented on a Samsung LCD monitor, situated approximately 50 cm from the participant. Stimulus display was synchronized to the screen refresh rate (10 ms). Responses were collected with an external response pad with three response keys, of which the two end keys were marked as **+** and **–**.

Each participant completed 320 trials, with a self-paced break after every 80 trials, resulting in 4 blocks. The first block was preceded by 16 practice trials and each block was preceded by 2 warm-up trials. In the unmasked condition, each trial started with a fixation sign (+) presented for 250 ms, which was followed by the lowercase prime for 200 ms, followed by a 40 ms blank, then the target in uppercase letters. In the masked condition, each trial started with a 500 ms forward mask (consisting of 12 # signs), then a prime in lowercase presented for 50 ms, which was immediately followed by the target in uppercase letters. In both mask conditions, the target remained on the screen until the participant's response, or timed out after 2,000 ms. Feedback was given only on trials where participants made an error. Each response was followed by an intertrial interval of 730 ms. If the response was incorrect, *wrong* was displayed for 350 ms during the intertrial interval.

At the outset of the experiment, participants were informed that their task was to categorize the uppercase word as being a "word" or "not a word". In the masked condition, no mention was made of the presence of the prime, and in the unmasked condition, no mention was made of the relatedness of the prime and target. Participants were instructed to keep their index fingers on the two end buttons of the response pad. Participants pressed the + button for word targets and the − button for nonword targets.

Participants received different random order of trials. Prime and target were presented in the center of the screen in black letters on a white background, using the 11-point Courier font. Feedback was also presented in black, just below of the center of the screen.

Results

In both Experiment 1 and 2, in the analysis of mean RT, the preliminary treatment of RT data was as follows. Error trials were excluded from the RT analysis. To reduce the effect of extremely short and long RTs, RTs greater than or equal to 3 standard deviations from the participant's individual mean RT were replaced by the relevant cut-off value. This affected 1.5% of the trials in Experiment 1. In the analysis of mean RT, a two-way analysis of variance (ANOVA) was used, with the factors prime relatedness (semantically related vs. unrelated) and mask (masked vs. unmasked). In the by-subjects analysis (F_1), prime relatedness was a within-subject factor and mask a between-subject factor; in the by-items analysis (F_2), both were within-item factors. An α level of .05 was used. The mean RTs, standard errors and error rates are presented in Table 1.

Table 1.

Mean response latency (in Milliseconds), Standard Errors, and Percentage Error Rates (%E) in Experiment 1 (Lexical Decision Task)

	Prime relatedness							
	Semantically related			Semantically unrelated			Priming effect	
Mask condition	RT	*SE*	%E	RT	*SE*	%E	In ms	%E
Masked	584	14.53	6.72	585	13.56	7.93	1	1.21
Unmasked	540	17.65	5.08	580	19.11	9.17	40***	4.09**

Note. RT = reaction time.
*** $p < .001$; ** $p < .01$

Analysis of mean RT*.* The main effect of prime relatedness averaged over mask conditions was significant ($F_1(1,57) = 24.27$, $p < .001$, $\eta^2 = .299$; $F_2(1,79) = 7.02$, $p < .05$, $\eta^2 = .082$), with faster RTS in the semantically related than unrelated condition, i.e., a semantic priming effect was found. The main effect of mask was non-significant by subjects ($F_1(1,57) = 1.16$, $p = .286$, $\eta^2 = .020$, but was significant by items $F_2(1,79) = 22.06$, $p < .001$, $\eta^2 = .218$). Critically, prime relatedness interacted with mask ($F_1(1,57) =$

21.10, $p < .001$, $\eta^2 = .270$; $F_2(1,79) = 23.07$, $p < .001$, $\eta^2 = .226$). Planned contrasts revealed that this interaction reflected a highly robust (40 ms) semantic priming effect when primes were unmasked ($F_1(1,29) = 35.70$, $p < .001$, $\eta^2 = .552$; $F_2(1,79) = 17.96$, $p < .001$, $\eta^2 = .185$), and a weak (1 ms) and non-significant masked semantic priming effect ($F_1(1,28) = 0.08$, $p = .782$, $\eta^2 = .003$; $F_2(1,79) = 0.15$, $p = .705$, $\eta^2 = .002$).

Error rate. The main effect of prime relatedness was significant by subjects ($F_1(1,57) = 14.69$, $p < .001$, $\eta^2 = .205$, but not by items $F_2(1,79) = 2.78$, $p = .100$, $\eta^2 = .034$), with fewer errors in the related than unrelated prime condition. The main effect of mask was non-significant ($F_1(1,57) = 0.03$, $p = .865$, $\eta^2 = .001$; $F_2(1,79) = 0.09$, $p = .765$, $\eta^2 = .001$). The interaction between prime relatedness and mask was significant ($F_1(1,57) = 4.34$, $p < .05$, $\eta^2 = .071$; $F_2(1,79) = 4.06$, $p < .05$, $\eta^2 = .049$). Consistent with the RT data, the semantic priming effect was significant in the unmasked condition ($F_1(1,29) = 14.24$, $p < .01$, $\eta^2 = .329$; $F_2(1,79) = 5.30$, $p < .05$, $\eta^2 = .063$), but no priming effect was found when primes were masked ($F_1(1,28) = 2.03$, $p = .165$, $\eta^2 = .068$; $F_2(1,79) = 0.52$, $p = .475$, $\eta^2 = .006$).

RT distribution analysis. In both Experiment 1 and 2, the correct RTs were analysed with QMPE (version 2.18, Cousineau, Brown, & Heathcote, 2004). To calculate the quantile estimates, RTs were sorted from fastest to slowest and subsequently divided into five equal-sized bins (fastest 20%, next fastest 20%, etc.) for each participant and condition. The average RT of the last trial of the lower bin and the first trial of the higher bin, make up the four observed quantile estimates generated by QMPE. Only the first trial of the highest quantile is used to calculate the quantile estimate for the last quantile, the quantile estimates are therefore not unduly affected by the extremely fast or slow outliers, and hence RT data were not trimmed for outliers in generating the quantiles.

The quantile plots averaged over the participants per condition for Experiment 1 are presented in Figure 1. For ease of comparison between the two mask conditions, we also plotted the semantic priming effect (i.e., the difference between the semantically unrelated and related prime condition) as a function of quantiles in the bottom panel in Figure 1. In this “delta plot”, a positively sloped line indicates an overadditive interaction between prime relatedness and quantile, i.e., a semantic priming effect that increases across quantiles. It is apparent from Figure 1 that while the semantic priming effect increases across quantiles in the unmasked condition, it is absent throughout the quantiles in the masked condition.

The pattern apparent in the quantile plots is supported by the analysis of RT distribution as a 4 (quantile) x 2 (prime relatedness: related vs. unrelated) x 2 (mask: masked vs. unmasked) factorial design, with quantile and prime relatedness as within-subject factors and mask as a between-group factor. Consistent with the mean RT analysis, the main effect of prime relatedness was significant ($F(1,57) = 30.83$, $p < .001$, $\eta^2 = .351$), as was the interaction between prime relatedness by mask ($F(1,57) = 28.01$, $p < .001$, $\eta^2 = .330$), which reflected the significant semantic priming effect in the unmasked prime condition ($F(1,29) = 51.09$, $p < .001$, $\eta^2 = .638$) and the non-significant semantic priming effect observed in the masked prime condition ($F(1,28) = 0.04$, $p = .843$, $\eta^2 = .001$). The main effect of mask was non-significant ($F(1,57) = 1.27$, $p = .264$, $\eta^2 = .022$). Overall, the semantic priming effect did not increase with quantile, as demonstrated by the non-significant prime relatedness x quantile interaction ($F(3,171) = 1.40$, $p = .245$, $\eta^2 = .024$). However, this was qualified by mask, as indicated by a significant, three-way interaction of prime relatedness, mask and quantile ($F(3,171) = 5.77$, $p < .01$, $\eta^2 = .092$). For the unmasked condition, the semantic priming effect increased across quantiles as indicated by the significant prime relatedness by quantile interaction ($F(3,87) = 4.34$, $p < .01$, $\eta^2 = .130$). In contrast, for the masked condition, prime relatedness did not interact with quantiles ($F(3,84) = 2.24$, $p = .090$, $\eta^2 = .074$).

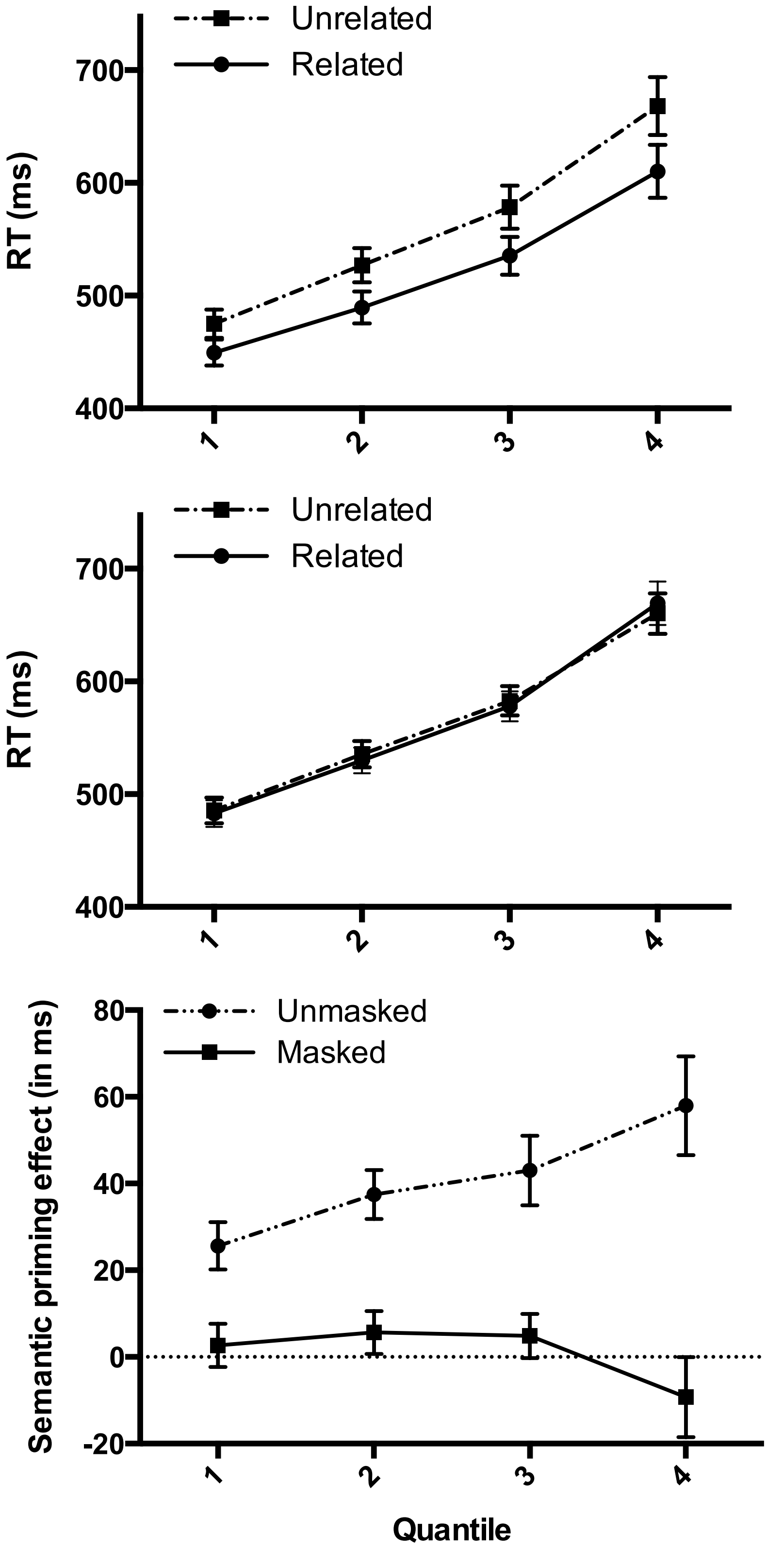

Figure 1. RT distribution of Experiment 1 (lexical decision task). Top panel = unmasked primes; middle panel = masked primes. The bottom panel shows the semantic priming effects for the two mask conditions. The error bars represent the standard error of the mean (SEM).

Discussion

The results of Experiment 1, using the lexical decision task, supported all three predictions made at the outset of the experiment. First, with unmasked (visible) primes presented at a short prime–target SOA, robust semantic priming effects were found. Second, the analysis of RT distribution revealed that the semantic priming effect found with unmasked primes increased across the quantiles, which is consistent with previous studies that used a short SOA and/or used prime–target pairs with backward association (e.g., Balota et al., 2008; Gomez et al., 2013; Hutchison et al., 2014; Thomas et al., 2012). This pattern has been identified with the use of the retrospective semantic matching strategy, in which finding a semantic relationship between the target and the prime biases the decision that the target is a word. Third, masking the prime eliminated the semantic priming effect. This is consistent with De Groot's (1983) study, which showed that the "mediated priming effect" (where the prime and target are indirectly related, mediated by an intervening word e.g., *lion–(tiger)–stripes*), found with a short prime–target SOA was eliminated when the prime was masked. Taken together, the results indicate that the semantic priming effect found in the lexical decision task with unmasked primes at a short SOA is produced by the retrospective semantic matching strategy. Additionally, masking the prime circumvents this strategy, because it is not possible to assess the relationship between words if participants are not aware that there are in fact two words.

In sum, the results of Experiment 1 are entirely as we predicted from the view that the semantic priming effect found with the lexical decision task reflects the retrospective semantic matching strategy, not the automatic spreading activation process.

Semantic Priming in the Semantic Categorization Task

The results of Experiment 1 using the lexical decision task showed that masking the prime eliminated the semantic priming effect, consistent with the absence of reliable semantic priming effects with masked primes reported in the literature we reviewed in the Introduction (e.g., Rastle et al., 2000). We also noted in the Introduction that in contrast to the studies using the lexical decision task, recent studies using semantic categorization tasks have reported finding semantic priming effects with masked primes. In this section, we first review these studies, with a view to identifying the boundary conditions for finding the semantic priming effect. We then discuss these boundary conditions within our theory of semantic priming in the semantic categorization task in terms of evidence accumulation and source confusion.

Dehaene et al.'s (1998) study was instrumental in re-establishing the finding of semantic priming with masked primes. The authors (see also Kouider & Dehaene, 2007) made an important point that subliminal semantic processing can be found under conditions where the task performed on the target is strategically applied to the prime. Support for the notion that masked primes are semantically processed in semantic tasks came from the category congruity effect. In Dehaene et al.'s study, participants categorized number targets (presented as spelt-out words, e.g., *ONE, EIGHT*, or as Arabic numerals, e.g., 1, 8) as smaller or larger than 5. Responses were faster when the masked prime preceding the target belonged to the same category (smaller/bigger than 5) compared to when it was category-incongruent. Moreover, the study was the first to use brain imaging (fMRI and event-related potentials/ERPs) to show that subliminal stimuli produced detectable neural activity in the motor cortex. Dehaene et al. (1998) interpreted the brain imaging data as evidence that the prime was processed semantically, then all the way to the motor response level, causing response competition.

As mentioned in the Introduction, the semantic nature of this effect was questioned after an important methodological issue in Dehaene et al.'s study was identified. Because the set of single-digit numbers is limited, Dehaene et al. used a small set of stimuli repeatedly, and the primes had previously been responded to as targets. Damian (2001) argued that such "used primes" become associated with a motor response (e.g., "press the key with the right index finger") based on his own finding using a size judgment task. In this task, participants judged whether words (e.g., *apple, coin, guitar*) denoted objects that were smaller/bigger than an arbitrary reference (20 cm x 20 cm). Damian (2001) reported that a congruity effect (e.g., *apple–coin* < *guitar–coin*) did not develop until the prime had been used as a target and had thus become associated with a response. This led him to question the semantic origin of the congruity effect observed by Dehaene et al. (1998) in the RT and the brain imaging measures, and suggested that these measures may have reflected the activation of the associated motor response instead. However, subsequent studies using number stimuli have shown that primes that had not been used as targets—the so-called "novel primes"—produce reliable category congruity effects (e.g., Kinoshita & Hunt, 2008; Kunde, Kiesel, & Hoffman, 2003; Reynvoet, Gevers, & Caessens, 2005; see Van den Bussche, et al., 2009 for a meta-analysis). These findings thus provide support for Dehaene et al.'s claim that category congruity effects obtained in semantic categorization tasks reflect semantic processing of the masked prime.

The Importance of Semantic Feature Overlap

To summarize the findings reviewed so far, reliable category congruity effects have been obtained that cannot be explained in terms of stimulus-response mapping. Nevertheless, these findings were generally obtained with stimuli that belong to a small, and often finite, set such as "(single) numbers bigger/smaller than 5", and "planets", and some (e.g., Forster, 2004; Forster, Mohan & Hector, 2003) have cast doubt on the generalizability of the category congruity effects to larger categories like "animals" or "man-made things" which are standardly used in studies of word recognition. According to Forster (2004), category congruity effects with masked primes are more readily obtained with small categories like "numbers bigger/smaller than 5" and "planets", because participants can enumerate the category members based on the category label and easily generate expectancies regarding the target. While this strategy works with small categories, it is not feasible with large categories, which contains too many exemplars to be enumerated.

In contrast, Quinn and Kinoshita (2008) argued that the critical factor accounting for the difference in category congruity effects is the category structure. Category congruity effects are more readily observed with small categories because small categories have a homogeneous category structure, whereas large categories are more heterogeneous. A small category comprises relatively few features that tend to be shared by most members; and members vary little in typicality. In contrast, large categories like "living things" often constitute a superordinate category that subsumes many heterogeneous subcategories like "birds", "fish", and "mammals". This means that semantic features comprising a large category are diverse: for example it subsumes bird features like <flies> and <has wings>, but also mammal features like <has four legs> and <has fur>. This heterogeneity means that there may be little overlap in the semantic features between two randomly selected members of a large category (e.g., mole and eagle). Consistent with this, Quinn and Kinoshita (2008) found that category congruity effects can be found with large categories like "animals" if the prime and target shared many semantic features like "hawk" and "eagle", but that it is not sufficient for the prime and target to simply belong to the same superordinate category as in "mole" and "eagle". To reiterate, category congruity effects with masked primes can be found irrespective of category size, provided that the prime and target share many semantic features.

The importance of semantic feature overlap in producing semantic priming effects, under conditions in which strategic use of the prime is ruled out, has also been pointed out previously by McRae and Boisvert (1998). They noted that previous studies (e.g., Lupker, 1984; Shelton & Martin, 1992) had reported that semantic priming effects could not be found with prime–target pairs that did not have an associative relationship under conditions that precluded the use of strategies and hence semantic priming effects were attributable to automatic processes only. McRae and Boisvert pointed out that the semantically related word pairs used in these studies (e.g., *duck–cow; nose–hand*) shared category membership (e.g., duck and cow are both farm animals, nose and hand are both body parts), but had little semantic feature overlap (e.g., a duck flies, but a cow does not; a cow produces milk, but a duck does not, etc.). With a new set of stimuli, judged by independent raters to share more semantic features, McRae and Boisvert obtained robust automatic semantic priming effects in a semantic categorization task. We also note that Bueno and Frenck-Mestre (2002) also reported finding category-congruency effects with masked primes using prime–target pairs with high semantic overlap (e.g., *boat–ship*) in a semantic categorization task with very large categories (concrete vs. abstract words).

Semantic Priming as Evidence Accumulation and Source Confusion

The literature reviewed so far has identified two conditions under which reliable masked semantic priming effects can be found: 1) the task used is semantic categorization, and 2) the semantic feature overlap between prime and target is high. We now turn to our theory of semantic priming in semantic categorization (De Wit & Kinoshita, 2014a) and discuss why semantic feature overlap is important for finding the masked semantic priming effect.

De Wit and Kinoshita (2014a) argued that semantic priming effects in the semantic categorization task are best explained in terms of evidence accumulation and source confusion, notions borrowed from the Bayesian reader account of masked priming (Norris & Kinoshita, 2008) and the ROUSE (Responding Optimally to Unknown Sources of Evidence, Huber, Shiffrin, Lyle, & Ruys, 2001) model of short-term priming. The Bayesian Reader (Norris, 2006; 2009) regards word recognition as a process of evidence accumulation for a hypothesis dictated by the task. In a semantic categorization task, the hypothesis is "the target is a member of the category (e.g., "an animal"), and the task may be viewed as a process of accumulating evidence where the evidence consists of the target's semantic features such as <has four legs> and <has fur> that are diagnostic of its category membership (see e.g., Grondin, Lupker, & McRae, 2009; Smith, Shoben & Rips, 1974, for findings consistent with the view that categorization decisions are based on distributed semantic features). Consistent with the ROUSE model, De Wit and Kinoshita (2014a) suggested that the priming effects reflect the "source confusion" between the prime and target. Due to its close spatial and temporal proximity to the target, evidence is accumulated from the prime, and is combined with that accumulated from the target (i.e., the source is confused). When related prime–target pairs share many semantic features (e.g., *hawk–EAGLE; sofa–COUCH*), the prime provides a head-start to the evidence accumulation process, facilitating the categorization decision to the target. De Wit and Kinoshita (2014a) presented support for the head-start view by means of an analysis of RT distribution, showing that the semantic priming effect was reflected in an overall distributional shift—the size of the semantic priming effect was constant across the quantiles.

De Wit and Kinoshita's (2014a) semantic categorization study used visible primes, but their theory of semantic priming should apply equally well to masked primes. According to their theory, (and consistent with the assumption of the ROUSE model), source confusion is automatic. That is, evidence may be accumulated from any prime that is in close spatial and temporal proximity to the target, whether or not the prime is masked and hence veiled from conscious awareness. As such, in semantic categorization, masking the prime should make little appreciable difference to semantic priming effects. Further, masked semantic priming effects in the semantic categorization task should show the same RT distribution pattern as unmasked primes. That is, masked semantic priming effects should be reflected in an overall distributional shift just as the pattern reported in De Wit and Kinoshita's (2014a) study that used unmasked, visible primes.

Experiment 2

To summarize, we have put forward the view that in the semantic categorization task the semantic priming effect reflects source confusion: Semantic features are accumulated from the prime and are used together with the features accumulated from the target to make the category decision to the target. When the prime and the target share many semantic features as in "hawk–EAGLE", the overlapping semantic features (e.g., <lays eggs>, <flies>) originating in the prime provide a head-start to the decision-making process. Under the assumption that the source confusion between the prime and the target occurs regardless of the prime's visibility, we expect to find reliable semantic priming effects with masked primes as well as unmasked primes in the semantic categorization task. In Experiment 2, we put this account to a test, using the same prime–target pairs used in Experiment 1 in a semantic categorization task. In addition, we analyse the RT distribution, and following De Wit and Kinoshita (2014a), we expect the semantic priming effect to show the head-start pattern, that is, the size of the semantic priming effect to remain constant across the quantiles.

Method

Participants. Sixty-four undergraduate students of Macquarie University in Sydney, 56 women and 8 men (M_{age} = 24.2 years) enrolled in cognitive psychology courses, participated in Experiment 2, in return for course credit. All participants had normal or corrected-to-normal vision. Of those, data from three participants were excluded because of a high (over 20%) error rate.

Design and stimuli. The design was the same as in Experiment 1, except that a semantic categorization task ("Animals") was used. The critical stimuli were the 40 animal name pairs and 40 man-made item pairs used as the critical prime–target pairs in Experiment 1. In addition, 80 filler trials were used, of which half were animal and half nonanimal targets. To ensure 50% of the trials consisted of related prime–target pairs, half of the 80 filler trials were pairs with related primes and half were paired with unrelated primes. The animal filler targets had an average length of 6.6 letters and LgSUBTLCD of 1.83, the nonanimal filler targets an average length of 6.3 letters and LgSUBTLCD of 2.4. Not all animal words appeared in the McRae et al. (1997) norms, so for the filler trials the average relatedness was verified using the LSA norms (Landauer, et al., 2007) According to LSA the average relatedness of the filler trials was 0.17 (0.16 for the animal and 0.18 for the nonanimal filler targets). Each participant completed 160 trials, preceded by 16 practice and 4 warm-up trials. A self-paced break was included after 80 trials, resulting in 2 blocks.

Apparatus and procedure. The apparatus and procedure was the same as in Experiment 1, except that in Experiment 2 primes and targets were presented in white letters on a black background, and the monitor used in the unmasked prime condition was a CRT instead of an LCD monitor with a screen refresh rate of 13.33 ms.[2] The monitors used and the screen refresh rates for the masked prime conditions were identical in Experiments 1 and 2.

Results

The preliminary treatment of outliers in the RT data for the mean RT analysis was identical to Experiment 1, and affected 1.6% of the trials in Experiment 2. The mean RT, SE and error rates for Experiment 2 are presented in Table 2. As in Experiment 1, the analysis of mean RT involved the factors prime relatedness (related vs. unrelated) and mask (masked vs. unmasked).

Analysis of mean RT. The main effect of prime relatedness was significant ($F_1(1,58) = 56.67$, $p < .001$, $\eta^2 = .494$; $F_2(1,79) = 38.73$, $p < .001$, $\eta^2 = .329$). The main effect of mask was non-significant by subjects ($F_1(1,58) = 0.89$, $p = .350$, $\eta^2 = .015$, but significant by items $F_2(1,79) = 10.20$, $p < .01$, $\eta^2 = .114$). Unlike the lexical decision task used in Experiment 1, the prime relatedness by mask interaction was non-significant ($F_1(1,58) = 3.04$, $p = .086$, $\eta^2 = .050$; $F_2(1,79) = 1.12$, $p = .293$, $\eta^2 = .014$). Importantly, the semantic priming effect was significant with both the unmasked prime ($F_1(1,28) = 34.66$, $p < .001$, $\eta^2 = .553$; $F_2(1,79) = 23.72$, $p < .001$, $\eta^2 = .231$) and masked prime conditions ($F_1(1,30) = 21.28$, $p < .001$, $\eta^2 = .415$; $F_2(1,79) = 17.36$, $p < .001$, $\eta^2 = .180$).

Error rate. The main effect of prime relatedness was significant by items, but not by subjects ($F_1(1,58) = 2.05$, $p = .157$, $\eta^2 = .034$; $F_2(1,79) = 4.02$, $p < .05$, $\eta^2 = .048$), as was the main effect of mask ($F_1(1,58) = 2.87$, $p = .096$, $\eta^2 = .047$; $F_2(1,79) = 4.12$, $p < .05$, $\eta^2 = .050$). The interaction between prime relatedness and mask was non-significant

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[2] Note that the difference in screen refresh rate did not alter the duration of the unmasked prime from that used in Experiment 1, but it did change the intertrial interval from 730 ms to 971 ms, and the feedback duration (presented only if the response was incorrect) from 350 ms to 466 ms.

(F_1(1,58) = 0.17, p = .679, η^2 = .003; F_2(1,79) = 0.23, p = .631, η^2 = .003). The semantic priming effect was non-significant with both the unmasked prime (F_1(1,28) = 1.06, p = .312, η^2 = .037; F_2(1,79) = 2.27, p = .136, η^2 = .028) and masked prime conditions (F_1(1,30) = 1.12, p = .299, η^2 = .036; F_2(1,79) = 1.49, p = .225, η^2 = .019).

Table 2.

Mean response latency (in Milliseconds), Standard Errors, and Percentage Error Rates (%E) in Experiment 2 (Semantic Categorization Task)

	Prime relatedness							
	Semantically related			Semantically unrelated			Priming effect	
Mask condition	RT	*SE*	%E	RT	*SE*	%E	In ms	%E
Masked	606	17.52	4.52	628	18.79	5.32	22***	0.80
Unmasked	578	14.86	5.95	613	13.68	7.41	35***	1.46

Note. RT = reaction time.
*** $p < .001$

RT distribution analysis. As in Experiment 1, the RT distribution was analysed using a 4 (quantile) x 2 (prime relatedness: related vs. unrelated) x 2 (mask: masked vs. unmasked) factorial design, with quantile and prime relatedness as within-subject factors and mask as a between-group factor. The quantile and delta plots for Experiment 2 are presented in Figure 2. It is apparent from the figure that the semantic priming effect is present in the masked condition as well as the unmasked condition, and that in both mask conditions, the semantic priming effect remains constant in size across the quantiles. These patterns are supported by the three-way ANOVA with quantile, prime relatedness, and mask as factors.

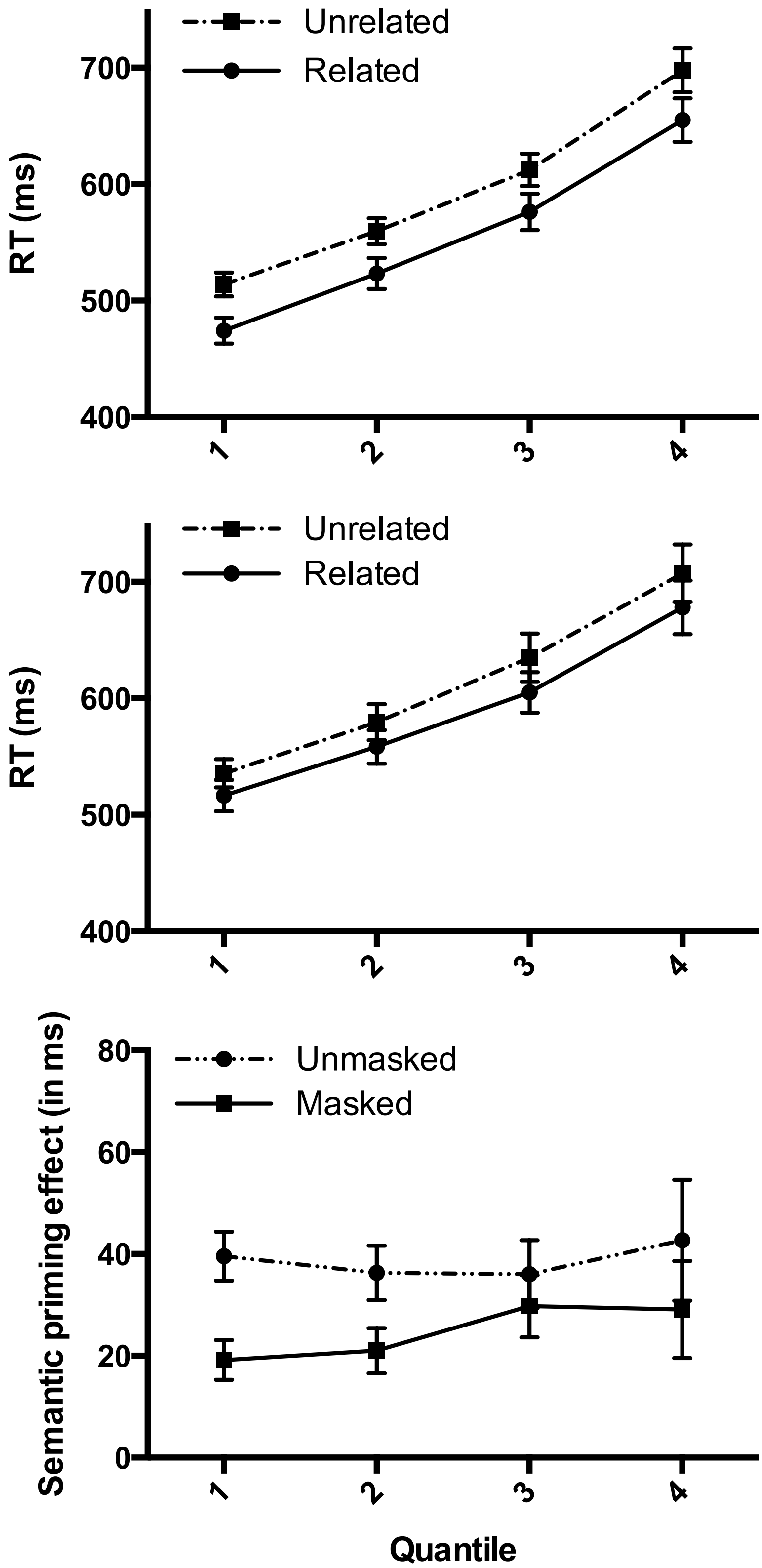

Figure 2. RT distribution of Experiment 2 (semantic categorization task). Top panel = unmasked primes; middle panel = masked primes. The bottom panel shows the semantic priming effects for the two mask conditions. The error bars represent the standard error of the mean (SEM).

As in the analysis of mean RT, the main effect of prime relatedness was significant ($F(1,58) = 70.79$, $p < .001$, $\eta^2 = .550$). The main effect of mask was non-significant ($F(1,58) = 1.32$, $p = .255$, $\eta^2 = .022$), as was the interaction between prime relatedness and mask ($F(1,58) = 3.40$, $p = .070$, $\eta^2 = .055$). Of main interest, the size of the overall semantic priming effect did not increase with quantile, as demonstrated by the non-significant prime relatedness by quantile interaction ($F(3,174) = 0.80$, $p = .498$, $\eta^2 = .014$). Separate analyses of the unmasked condition and the masked condition showed that semantic priming was significant in the unmasked condition ($F(1,28) = 42.12$, $p < .001$, $\eta^2 = .601$) and in the masked condition ($F(1,30) = 27.73$, $p < .001$, $\eta^2 = .480$). The semantic priming effect remained constant across quantiles, as indicated by the non-significant prime relatedness by quantile interaction, both when primes were masked ($F(3,90) = 1.19$, $p = .318$, $\eta^2 = .038$) and unmasked ($F(3,84) = 0.31$, $p = .816$, $\eta^2 = .011$), as shown by the non-significant three-way interaction of prime relatedness, quantile and mask ($F(3,174) = 0.61$, $p = .609$, $\eta^2 = .010$).

Discussion

The main finding of Experiment 2 is that reliable semantic priming effects are found with the semantic categorization task, even when the primes are masked. Also, replicating De Wit and Kinoshita (2014a), RT distribution analysis of the semantic priming effect with unmasked primes showed that the semantic priming effect reflected a distributional shift (i.e., the semantic priming effect was constant across the quantiles). This is consistent with the notion that the semantic priming effect in semantic categorization reflects a head-start in the evidence accumulation process, due to source confusion. Importantly, the same RT distributional shift pattern was found when primes were masked, suggesting that the masked semantic priming effect is driven by the same head-start mechanism.

General Discussion

The present study investigated the mechanisms responsible for the semantic priming effects in the lexical decision task (Experiment 1) and semantic categorization task (Experiment 2) with masked and unmasked primes. The widely held view that semantic priming effects at short SOAs are driven by an *automatic* spreading activation process invites two predictions. First, from the view that automatic processes can occur without conscious awareness, it is expected that semantic priming effects should be found with masked primes as well as unmasked primes. Second, from the view that automatic processes are involuntary, it is expected that semantic priming effects "should not be modulated by differing task demands" (Neely, 1991, p.298). In direct contradiction to both of these assumptions, our study showed that masked semantic priming effects depend on the task used: While the semantic priming effect was eliminated by masking the prime in the lexical decision task, the same stimuli produced a reliable masked semantic priming effect in the semantic categorization task. In addition, the RT distribution analysis indicated that the pattern of semantic priming effects was different in lexical decision and semantic categorization. Below we explain these results by pointing out that *how* the semantic information is used to produce semantic priming effects differs between the two tasks.

In Experiment 1, using the lexical decision task, RT distribution revealed a pattern that has been identified with the retrospective semantic matching strategy, namely, an increasing semantic priming effect across quantiles (e.g., Thomas, et al., 2012). In this strategy, participants use the semantic relatedness of prime and target to guide the lexical (word–nonword) decision, capitalizing on the fact that (by design) only the word targets are semantically related to the prime. Assessment of the relationship between prime and target requires awareness of the prime's identity, which is prevented when primes are masked. Consistent with this, masking the prime eliminated the semantic priming effects in lexical decision: In the RT distribution analysis the semantic priming effect was absent throughout the quantiles.

In Experiment 2, we tested the notion that semantic priming effects in semantic categorization reflect source confusion during the evidence accumulation process. According to this account, semantic priming effects in semantic categorization reflect the semantic features contributed by the prime that are congruent with the target's semantic features used in making the categorization decision. To make a categorization decision (e.g., "this is an animal"), evidence in the form of distributed semantic features (e.g., <flies>, <lays eggs>) is accumulated from the target (see e.g., Grondin, et al., 2009, for findings consistent with this view). Due to the close spatial and temporal proximity of prime and target, evidence is accumulated from the prime also, and when the prime and target have overlapping semantic features (as in *hawk–EAGLE; sofa–COUCH*), these features provide a head-start to the evidence accumulation process. This interpretation was supported by the RT distribution analysis. With unmasked primes, replicating the pattern reported by De Wit and Kinoshita (2014a), the semantic priming effect was constant in size across the quantiles (i.e., the semantic priming effect reflected a shift of the RT distribution). De Wit and Kinoshita explained this pattern as reflecting the source confusion between the prime and the target's features that arises during the evidence accumulation process. Importantly, the same RT distribution pattern was found with masked primes, indicating that source confusion occurs with or without conscious awareness of the prime.

Taken together, the results of Experiment 1 and 2 indicate that the way in which the prime is used to produce semantic priming effects at short SOAs in the lexical decision task is different to that in the semantic categorization task. In the semantic categorization task, the semantic features accumulated from the prime are combined with those of the target (i.e., the source is confused). To the extent that the evidence from the prime and target is congruent (as would be the case with related prime–target pairs like *hawk–EAGLE*), a semantic priming effect is observed. In contrast, in the lexical decision task, it is the prime's relationship to the target (whether or not they are related) that is diagnostic of the target's lexical status, and it is this information that is used in making the decision required to the target (whether it is a word or a nonword) that produces the semantic priming effect. The task-specific decision processes govern how the prime's semantic information is used to assist the decision required to the target to produce semantic priming effects, and also how masking the prime impacts on the semantic priming effects.

Comparison to Gomez et al. (2013)

Our study is not the first to examine RT distribution analysis of masked and unmasked priming. Recently, Gomez et al. (2013) reported RT distribution analyses of identity priming (e.g., *table–TABLE*) and semantic priming and concluded that "masked priming is qualitatively different from unmasked priming" (p. 1738, discussion of the identity priming is beyond the scope of the present paper, and we will focus on semantic priming here.) Like our Experiment 1, Gomez et al. used the lexical decision task, and prime–target SOAs of 56 and 200 ms, comparable to our SOAs of 50 ms and 240 ms. Their RT distribution analysis showed that just as in our Experiment 1, the semantic priming effect increased across the quantiles when primes were unmasked; in contrast, with masked primes, the effect remained small and unreliable across the quantiles. Together with the identity priming effect, Gomez et al. took the latter as showing an overall distributional shift. Gomez et al. interpreted the RT distribution data within the diffusion model (Ratcliff, 1978; Ratcliff, Gomez & McKoon, 2004), according to which the distributional shift pattern obtained with masked primes is assumed to reflect a processing head-start, whereas the overadditive interaction between prime relatedness and quantile observed with the unmasked primes is assumed to reflect an increase in the rate of evidence accumulation (called the drift rate). More specifically, Gomez et al. interpreted the unmasked priming effects in terms of a compound cue model proposed by Ratcliff and McKoon (1988) in which prime and target are merged to form a compound cue, and the strength of this cue is used to drive the evidence accumulation process in the lexical decision task.

With regards to the lexical decision task, while the language used to describe the compound cue model is different from the retrospective semantic matching strategy, we see no real contradiction between the two. In the retrospective semantic matching strategy, the relatedness between the prime and target is used as one of the cues diagnostic of the target's lexical status. In the compound cue model also, the semantically related prime is assumed to increase the "word-likeness" of the target that is assumed to drive the word–nonword discrimination process. To put it another way, both the retrospective semantic matching strategy and the compound cue model regard the relatedness between the target and the prime as one of the sources of evidence that is used in combination with other evidence to drive the decision that the target is a word. As such, both accounts can explain the RT distribution pattern of the semantic priming effect—increasing across the quantiles—observed with the unmasked primes in the lexical decision task.

Where our account differs from Gomez et al.'s proposal relates to the task-dependent nature of priming. Gomez et al. posit that "masked related primes give a head start to the processing of the target compared to unrelated primes, while unmasked priming affects primarily the quality of lexical information" (Abstract, p. 1731). Our semantic categorization data clearly argue against this view, as here, both the masked and unmasked primes showed the same RT distributional shift pattern, which Gomez et al. identified as a head-start.

This discrepancy between our view and Gomez et al.'s (2013) view stems from the fact that Gomez et al. studied the masked and unmasked priming effects using just one task: Lexical decision. At the core of our proposal is that priming effects are task-dependent. The decision processes in the lexical decision task differ from those in the semantic categorization task. It follows from this that the way in which a semantically related prime is used to assist the decision to the target, and hence how the semantic priming effect is reflected in the RT distribution, is different in the two tasks. The two experiments presented here—Experiment 1 using lexical decision and Experiment 2 using semantic categorization—together show clearly that it is the decision required by the task, not the visibility of the prime, that governs the nature of semantic priming revealed in the RT distribution patterns.

Conclusion

Semantic priming effects obtained with a short prime–target SOA are standardly explained in terms of the automatic spreading activation process. Contrary to its assumption that semantic priming should occur without conscious awareness of the prime, masking the prime eliminated the semantic priming effect in the lexical decision task, but in the semantic categorization task, both masked and unmasked primes produced robust semantic priming effects. RT distribution analysis further showed that the RT distribution patterns of the semantic priming effects are task-dependent, reflecting the different processes that underlie semantic priming effects in lexical decision and semantic categorization. We suggest that the automatic spreading activation process does not have adequate explanatory power to account for these findings, and semantic priming effects are instead better explained in terms of the evidence accumulation process that is guided by the task, and source confusion between the prime and the target.

References

Balota, D. A., & Yap, M. J. (2011). Moving beyond the mean in studies of mental chronometry: The power of response time distributional analyses. *Current Directions in Psychological Science, 20*, 160-166.

Balota, D. A., Yap, M. J., Cortese, M. J., & Watson, J. M. (2008). Beyond mean response latency: Response time distributional analysis of semantic priming. *Journal of Memory and Language, 59*, 495-523.

Balota, D. A., Yap, M. J., Cortese, M. J., Hutchison, K. A., Kessler, B., Loftis, B., Neely, J. H., Nelson, D. L., Simpson, G. B., & Treiman, R. (2007). The English Lexicon Project. *Behavior Research Methods, 39*, 445-459.

Brysbaert, M., & New, B. (2009). Moving beyond Kuçera and Francis: A critical evaluation of current word frequency norms and the introduction of a new and improved word frequency measure for American English. *Behavior Research Methods, 41*, 977-990.

Bueno, S., & Frenck-Mestre, C. (2002). Rapid activation of the lexicon: A further investigation with behavioral and computational results. *Brain & Language, 81*, 120-130.

Bueno, S., & Frenck-Mestre, C. (2008). The activation of semantic memory: Effects of prime exposure, prime-target relationship, and task demands. *Memory & Cognition, 36*, 882-898.

Collins, A. M., & Loftus, E. F. (1975). A spreading-activation theory of semantic processing. *Psychological Review, 82*, 407-428.

Cousineau, D., Brown, S. [D.], & Heathcote, A. (2004). Fitting distributions using maximum likelihood: Methods and packages. *Behavior Research Methods, Instruments, & Computers,* 36, 742-756.

Damian, M. F. (2001). Congruity effects evoked by subliminally presented primes: automaticity rather than semantic processing. *Journal of Experimental Psychology: Human Perception and Performance, 27*, 154-165.

De Groot, A. M. B. (1983). The range of automatic spreading activation in word priming. *Journal of Verbal Learning and Verbal Behavior, 22*, 417-436.

De Groot, A. M. B. (1984). Primed lexical decision: Combined effects of the proportion of related prime–target pairs and the stimulus-onset asynchrony of prime and target. *The Quarterly Journal of Experimental Psychology Section A, 36*, 253-280.

De Wit, B., & Kinoshita, S. (2014a, February 24). Relatedness proportion effects in semantic categorization: Reconsidering the automatic spreading activation process. *Journal of Experiment Psychology: Learning, Memory, and Cognition.* Advance online publication. doi: 10.1037/xlm0000004

De Wit, B., & Kinoshita, S. (2014b). An RT distribution analysis of relatedness proportion effects in lexical decision and semantic categorization reveals different mechanisms. *Memory & Cognition.* doi: 10.3758/s13421-014-0446-6

Dehaene, S., Naccache, L., Le Clec'H, G., Koechlin, E., Mueller, M., Dehaene-Lambertz, G., Van de Moortele, P.F., & Le Bihan, D. (1998). Imaging unconscious semantic priming. *Nature, 395*, 597-600.

Forster, K. I. (2004). Category size effects revisited: frequency and masked priming effects in semantic categorization. *Brain & Language, 90*, 276-286.

Forster, K. I., & Davis, C. (1984). Repetition priming and frequency attenuation in lexical access. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 10*, 680-698.

Forster, K. I., & Forster, J. C. (2003). DMDX: A windows display program with millisecond accuracy. *Behavior Research Methods, Instruments, and Computers, 35*, 116-124.

Forster, K. I., Mohan, K., & Hector, J. (2003). The Mechanics of Masked Priming. In S.

Kinoshita & S. Lupker (Eds.), *Masked priming: The state of the art* (pp. 3-37). New York: Psychology Press.

Fowler, C. A., Wolford, G., Slade, R., & Tassinary, L. (1981). Lexical access with and without awareness. *Journal of Experimental Psychology: General, 110*, 341-362.

Frenck-Mestre, C., & Bueno, S. (1999). Semantic features and semantic categories: Differences in rapid activation of the lexicon. *Brain and Language, 68*, 199-204.

Gomez, P., Perea, M., & Ratcliff, R. (2013). A diffusion model account of masked vs. unmasked priming: Are they qualitatively different? *Journal of Experimental Psychology: Human Perception and Performance*, *39,* 1731-1740.

Grondin, R., Lupker, S.J., & McRae, K. (2009). Shared features dominate semantic richness effects for concrete concepts. *Journal of Memory and Language, 60*, 1-19.

Holender, D. (1986). Semantic activation without conscious identification in dichotic listening, parafoveal vision, and visual masking: A survey and appraisal. *Behavioral and Brain Sciences, 9*, 1-23.

Huber, D. E., Shiffrin, R. M., Lyle, K. B., & Ruys, K. I. (2001). Perception and preference in short-term word priming. *Psychological Review, 108*, 149-182.

Hutchison, K. A. (2007). Attentional control and the relatedness proportion effect in semantic priming. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 33*, 645-662.

Hutchison, K. A., Heap, S. J., Neely, J. H., & Thomas, M. A. (2014). Attentional control and asymmetric associative priming. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 40*, 844-856.

Kahan, T. A., Neely, J. H., & Forsythe, W. (1999). Dissociated backward priming effects in lexical decision and pronunciation tasks. *Psychonomic Bulletin & Review, 6*, 105-110.

Kinoshita, S., & Hunt, L. (2008). RT distribution analysis of category congruence effects with masked primes. *Memory & Cognition, 36*, 1324-1334.

Kinoshita, S., & Lupker, S.J. (Eds.) (2003). *Masked priming: The state of the art.* New York: Psychology Press.

Kouider, S., & Dehaene, S. (2007). Levels of processing during non-conscious perception: A critical review of visual masking. *Philosophical Transactions of the Royal Society B: Biological Sciences, 362*, 857-875.

Kunde, W., Kiesel, A., & Hoffman, J. (2003). Conscious control over the content of unconscious cognition. *Cognition, 88*, 223-242.

Landauer, T. K., McNamara, D. S., Dennis, S., & Kintsch, W. (2007). *Handbook of Latent Semantic Analysis.* Mahwah, NJ: Lawrence Erlbaum Associates, Publishers.

Lupker, S. J. (1984). Semantic priming without association: A second look. *Journal of Verbal Learning and Verbal Behavior, 23*, 709-733.

Marcel, A. J. (1983). Conscious and unconscious perception: Experiments on visual masking and word recognition. *Cognitive Psychology, 15*, 197-237.

Masson, M. E. J. (1995). A distributed memory model of semantic priming. *Journal of Experimental Psychology: Learning, Memory, amd Cognition, 21*, 3-23.

McNamara, T. P. (2005). *Semantic Priming: Perspectives from memory and word recognition.* New York: Psychology Press.

McRae, K., & Boisvert, S. (1998). Automatic semantic similarity priming. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 24*, 558-572.

McRae, K., Cree, G., Seidenberg, M., & McNorgan, C. (2005). Semantic feature production norms for a large set of living and nonliving things. *Behavior Research Methods, 37*, 547-559.

McRae, K., de Sa, V. R., & Seidenberg, M. S. (1997). On the nature and scope of featural representations of word meaning. *Journal of Experimental Psychology: General, 126*, 99-130.

Meyer, D. E., & Schvaneveldt, R. W. (1971). Facilitation in recognizing pairs of words: Evidence of a dependence between retrieval operations. *Journal of Experimental Psychology, 90*, 227-234.

Neely, J. H. (1976). Semantic priming and retrieval from lexical memory: Evidence for facilitatory and inhibitory processes. *Memory & Cognition, 4*, 648-654.

Neely, J. H. (1977). Semantic priming and retrieval from lexical memory: Roles of inhibitionless spreading activation and limited-capacity attention. *Journal of Experimental Psychology: General, 106*, 226-254.

Neely, J. H. (1991). Semantic priming effects in visual word recognition: A selective review of current findings and theories. In D. Besner & G.W. Humphreys (Eds.), *Basic processes in reading: Visual word recognition* (pp. 264-336). Hillsdale, NJ: Erlbaum.

Neely, J. H., & Kahan, T. A. (2001). Is semantic activation automatic? A critical re-evaluation. In H.L. Roediger, III, J.S. Nairne, I. Neath, & A.M. Suprenant (Eds.), *The nature of remembering: Essays in honor of Robert G. Crowder* (pp. 69-93). Washington, DC: American Psychological Association.

Neely, J. H., & Keefe, D. E., & Ross, K. L. (1989). Semantic priming in the lexical decision task: Roles of prospective prime-generated expectancies and retrospective semantic matching. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 15*, 1003-1019.

Norris, D. (2006). The Bayesian reader: Explaining word recognition as an optimal Bayesian decision process. *Psychological Review, 113,* 327-357.

Norris, D. (2009). Putting it all together: A unified account of word recognition and reaction-time distributions. *Psychological Review, 116,* 207-219.

Norris, D., & Kinoshita, S. (2008). Perception as evidence accumulation and Bayesian inference: Insights from masked priming. *Journal of Experimental Psychology: General, 137*, 434-455.

Perea, M., & Gotor, A. (1997). Associative and semantic priming effects occur at very short stimulus-onset asynchronies in lexical decision and naming. *Cognition, 62*, 223-240.

Posner, M. I., & Snyder, C. R. R. (1975). Attention and cognitive control. In R.L. Solso (Ed.), *Information processing and cognition: The Loyala symposium* (pp. 55-85). Hillsdale, NJ: Lawrence Erlbaum Associates, Inc.

Plaut, D. C., & Booth, J. R. (2000). Individual and Developmental Differences in Semantic Priming: Empirical and Computational Support for a Single-Mechanism Account of Lexical Processing. *Psychological Review, 107*, 786-823.

Quinn, W. M., & Kinoshita, S. (2008). Congruence effect in semantic categorization with masked primes with narrow and broad categories. *Journal of Memory and Language, 58*, 286-306.

Rastle, K., Davis, M., Marslen-Wilson, W., & Tyler, L.K. (2000). Morphological and semantic effects in visual word recognition: A time course study. *Language and Cognitive Processes, 15*, 507-538.

Ratcliff, R. (1978). A theory of memory retrieval. *Psychological Review, 85*, 59-108.

Ratcliff, R., Gomez, P., & McKoon, G. (2004). A diffusion model account of the lexical decision task. *Psychological Review, 111*, 159-182.

Ratcliff, R., & McKoon, G. (1988). A retrieval theory of priming in memory. *Psychological Review, 95*, 385-408.

Reynvoet, B., Gevers, W., Caessens, B. (2005). Unconscious primes activate motor codes through semantics. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 31*, 991-1000.

Shelton, J. R., & Martin, R. C. (1992). How semantic is automatic semantic priming? *Journal of Experimental Psychology: Learning, Memory, and Cognition, 18*, 1191-1210.

Smith, E. E., Shoben, E. J., & Rips, L. J. (1974). Structure and process in semantic memory: A featural model for semantic decisions. *Psychological Review, 81*, 214-241.

Thomas, M. A., Neely, J. H. & O'Connor, P. (2012). When word identification gets tough, retrospective processing comes to the rescue. *Journal of Memory and Language, 66*, 623-643.

Van den Bussche, E., Van den Noortgate, W., & Reynvoet, B. (2009). Mechanisms of masked priming: A meta-analysis. *Psychological Bulletin, 135*, 452-477.

Yap, M. J., Balota, D. A., & Tan, S. E. (2013). Isolating lexical and decision processes in the lexical decision task. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 39*, 140-158.

Chapter 5—General Discussion

General Discussion

The main goal of this thesis was to investigate the widely held view that semantic priming effects at short SOAs (generally less than 250 ms) are driven by an automatic spreading activation process, according to which semantic activation spreads *automatically* from the prime to the related target (e.g., Collins & Loftus, 1975). This automaticity notion of the semantic priming effect carries the assumptions that semantic priming is "uncontrollable or involuntary" and that semantic priming can "occur without conscious awareness" (e.g., Neely, 1991; Posner & Snyder, 1975). The research presented in this thesis tested these automaticity assumptions of semantic priming through the manipulation of relatedness proportion (RP), prime visibility (masked vs. unmasked), and the type of task (lexical decision vs. semantic categorization). On the assumption that semantic priming at a short SOA (240 ms) is automatic, none of these manipulations should impact on the magnitude of the semantic priming effect.

In addition to the mean RT, which is the unit of analysis standardly used in studies of semantic priming, the effects of the three manipulations on the RT distribution were also examined. There has been growing recognition in the semantic priming literature that RT distribution analyses are useful in refining the picture of the semantic priming effect, and its underlying mechanism(s) (e.g., Balota & Yap, 2011; Balota, Yap, Cortese, & Watson, 2008). In this thesis, I have adopted this approach to critically evaluate the automaticity notion of the semantic priming effect and explore the impact of the three mentioned manipulations on the RT distribution.

The main findings presented in this thesis directly contradicted the assumption that semantic priming at a short SOA is automatic, with all three manipulations—RP (low vs. high), prime visibility (masked vs. unmasked) and the type of task (lexical decision vs. semantic categorization)—impacting on the magnitude of the semantic priming effect. Furthermore, the way in which the semantic priming effect was reflected in the RT distribution, as well as the impact of RP and prime visibility on the RT distribution, were task-dependent, indicating that the semantic priming effects obtained in the lexical decision and semantic categorization tasks were driven by different underlying processes. Together, these findings were used to reconsider the notion of an automatic spreading activation process in explaining semantic priming effects at short SOAs. It was proposed that semantic priming effects are instead best explained in terms of task-dependent processes, namely source confusion in the semantic categorization task and retrospective semantic matching in the lexical decision task. Before discussing this alternate, task-dependent view, I will first provide an overview of the findings from each of the experimental chapters.

Overview of Chapters

Chapter 2—Relatedness Proportion Effects in Semantic Categorization: Reconsidering the Automatic Spreading Activation Process

The magnitude of the semantic priming effect is larger when the proportion of related prime–target pairs in the experiment (RP) is high relative to when it is low, a finding referred to as the Relatedness Proportion effect (RP effect, Tweedy & Lapinski, & Schvaneveldt, 1977). In Chapter 2, the RP effect was investigated at a short SOA (240 ms) in a semantic categorization task. Standardly, RP effects have been explained in terms of the expectancy generation strategy, in which the semantic properties of the prime are used to predict the identity of the upcoming target—a process that is assumed to take time and therefore cannot produce RP effects at short SOAs (e.g., Neely, 1991). In the lexical decision task, the task commonly used, the RP effect can alternatively be driven by the retrospective semantic matching strategy. In this strategy, *after* the target is presented but before a decision to the target is made, the meaning of the target is matched to that of the prime and the assessed relationship used to assist the decision to the target—a process that, due to its retrospective nature, can operate and produce RP effects at short as well as long SOAs (e.g., De Groot, 1984). In the semantic categorization task (e.g., "is the target an animal?"), the use of the retrospective semantic matching strategy is precluded, allowing the manipulation of RP at a short SOA to be a straightforward test of the automaticity of semantic priming. Therefore, in Experiment 1, the automaticity of semantic priming at a short SOA (240 ms) was investigated by manipulating RP (.25 vs. .75 related trials) in a semantic categorization task, which ensured that both the expectancy generation and the retrospective semantic matching strategies were precluded and the observed semantic priming effects therefore only attributable to the automatic spreading activation process. However, in direct contradiction to this automaticity notion of semantic priming, a robust RP effect was found in Experiment 1.

In Experiment 2, the possibility that the semantic priming effects obtained in Experiment 1 reflected a response cuing effect was tested. In Experiment 1, the semantically related prime–target pairs were selected on the basis of a high semantic feature overlap (e.g., *hawk–EAGLE; sofa–COUCH*), and the semantically unrelated pairs were generated by re-pairing the items so that they were category-incongruent (e.g., *sofa–EAGLE; hawk–COUCH*). The semantic relatedness of prime and target was thus confounded with category congruence and hence response congruence, allowing the possibility that participants used the prime's category to predict the response to the target. Therefore, in Experiment 2, prime–target pairs were selected to be category-congruent but otherwise semantically unrelated (e.g., *mole–EAGLE; rifle–COUCH*), and the proportion of category-congruent trials was manipulated. Although the results demonstrated that the size of the category congruity effect was modulated by congruence proportion, the pattern of results was very different from those of

Experiment 1. Specifically, whereas a large semantic priming effect was found in the high RP condition in Experiment 1, a small congruity effect was found in Experiment 2. Furthermore, in contrast to the weak and non-significant positive semantic priming effect found in the low RP condition in Experiment 1, a significant negative congruity effect was found in Experiment 2. The dissociation between these two experiments was taken as evidence that the semantic priming effects in Experiment 1 could not simply be explained as a response cuing effect due to category congruence.

An alternative account, based on the notions of evidence accumulation and source confusion, was proposed, according to which the semantic priming effect observed in semantic categorization reflects "source confusion". It is assumed that a semantic categorization decision (e.g., "the target is an animal") is made by accumulating evidence consisting of distributed semantic features from the target. Due to the prime's close spatial and temporal proximity to the target, evidence is also accumulated from the prime, that is, the source of evidence is confused. To the extent that the semantic features accumulated from the prime are shared by the target (e.g., *hawk* and *eagle* or *sofa* and *couch*), the evidence contributed by the prime is congruent with the decision required to the target; hence the prime provides a head-start to the evidence accumulation process for the target. Support for this head-start process was found in the RT distribution analysis, which revealed that the semantic priming effects in Experiment 1 were reflected in overall shifts of the RT distribution. The effect of RP was found to modulate the amount of distributional shift: In the high RP condition the amount of shift was greater. This RT distribution pattern was interpreted as a modulation of the amount of source confusion: The greater the RP, the more trials there are in which the evidence contributed by the prime is consistent with the decision to the target, hence it is more beneficial to combine the features of the prime with that of the target (i.e., increase the source confusion).

Chapter 3—An RT Distribution Analysis of Relatedness Proportion Effects in Lexical Decision and Semantic Categorization Reveals Different Mechanisms

In contrast to the general consensus that semantic priming effects at short SOAs are automatic, and hence should not be modulated by RP, De Groot (1984) reported a reliable RP effect at a short SOA (240 ms), using a lexical decision task. De Groot explained this surprising finding as reflecting the use of the retrospective semantic matching strategy (also see Neely, 1991). In the lexical decision task, the semantic relationship between prime and target is a viable indicator of the target's lexical status, as typically only the word targets are selected to be related to the word primes (nonword targets are typically paired with word primes that are not semantically related to the word that the nonword resembles). The use of this strategy is modulated by the nonword ratio, that is, the proportion of the trials in which the target is a nonword given the prime and target are unrelated (Neely, Keefe, & Ross, 1989). When a target in an unrelated prime–target pair is a nonword on a great proportion of trials, that is, when the nonword ratio is high, the absence of a prime–target relationship becomes a more useful indicator that the target may be a nonword. As Neely et al. (1989) pointed out, the nonword ratio is typically confounded with RP: As RP increases, nonword ratio increases. The RP effect obtained by De Groot can thus be explained as a nonword ratio effect, driven by an increased reliance on the retrospective semantic matching strategy. This process differs from the alternative view proposed in Chapter 2, in which it was suggested that the RP effect in semantic categorization reflects a greater amount of source confusion through a modulation of prime processing. In Chapter 3, RT distribution analyses were used to investigate whether the mechanisms underlying the RP effect in lexical decision differs from that in semantic categorization. Specifically, the effect of RP on the RT distribution in the lexical decision task was investigated and compared to the effect of RP on the RT distribution in the semantic categorization task observed in Experiment 1 of Chapter 2.

Semantic priming effects driven by retrospective use of the prime have been found to manifest themselves in the RT distribution as an increase in the skew of the RT distribution, with greater semantic priming effects in the tail of the RT distribution (e.g., Balota, et al., 2008; Thomas, Neely, & O'Connor, 2012). This RT distribution pattern stands in contrast to that found in the semantic categorization task in Experiment 1 of Chapter 2, in which the semantic priming effect was reflected in a distributional shift—a pattern that has been identified as source confusion. Building on this observed task-dependence, the RT distribution analyses of Chapter 3 demonstrated that the way in which RP modulated the size of the semantic priming effect was also dependent on the task used: While the RP effect in the lexical decision task was confined to the tail of the RT distribution, magnifying the semantic priming effect by affecting the skew of the RT distribution, the RP effect in the semantic categorization task manifested itself as an overall shift of the distribution, magnifying the semantic priming effect by a constant amount throughout the RT distribution.

This dissociation in RT distribution patterns was explained as reflecting the different decision process underlying the semantic priming effects in the two tasks. In the lexical decision task, it was argued that the retrospectively assessed semantic relationship between prime and target was one of the multiple sources of information used to drive the decision to the target. The effect of RP on the skew of the RT distribution was explained as reflecting the increased retrospective reliance on the prime in the high RP condition; when RP, and therefore nonword ratio, is high, the absence of a prime–target relationship is a more accurate indicator of the target's lexical status relative to when RP is low. In contrast, in the semantic categorization task, RP increases the usefulness of the prime by increasing the number of trials on which the evidence accumulated from the prime is similar to that from the target. When RP is high, it is more useful to pay attention to the prime, which increases the source confusion, which is in turn reflected in a large shift of the RT distribution.

Chapter 4—The Masked Semantic Priming Effect is Task-Dependent: Reconsidering the Automatic Spreading Activation Process

Whereas the automaticity assumption that semantic priming effects at a short SOA are "uncontrollable" was examined in Chapters 2 and 3, the automaticity assumption that semantic priming can "occur without conscious awareness" was investigated in Chapter 4. From the view that semantic priming at a short SOA reflects an automatic spreading activation process, and that an automatic process can "occur without conscious awareness", semantic priming effects should be obtained even when the prime's identity is veiled from conscious awareness. In other words, masking the prime should not impact on the semantic priming effect. In line with this assumption, masked semantic priming effects have been considered "one of the strongest pieces of evidence supporting an automatic spreading activation account" (p. 297, Neely, 1991). However, in contrast to the reliable semantic priming effects generally obtained with unmasked (visible) primes, masked semantic priming effects have typically been weak and unreliable, especially in the lexical decision task (e.g., Bueno & Frenck-Mestre, 2008; Perea & Gotor, 1997). These mixed reports pose the question that if semantic priming effects are driven by an automatic spreading activation process, then why are masked semantic priming effects so elusive? This was investigated in Chapter 4 by manipulating prime visibility, using both masked and unmasked primes in a lexical decision task (Experiment 1) and a semantic categorization task (Experiment 2), using the same related prime–target pairs that were used in Chapters 2 and 3.

In direct contradiction to the automaticity notion of semantic priming, the results demonstrated that masked semantic priming effects were task-dependent. In the lexical decision task, a reliable semantic priming effect was observed with unmasked primes, but the masked semantic priming effect was absent. In contrast, the same stimuli produced reliable masked and unmasked semantic priming effects in the semantic categorization task. In addition, the RT distribution analysis demonstrated that the semantic priming effects obtained in the lexical decision and semantic categorization tasks were reflected in different RT distribution patterns. In the lexical decision task, with unmasked primes, the semantic priming effect was reflected in an overadditive interaction pattern, with the semantic priming effect larger in the tail of the RT distribution. In contrast, in the semantic categorization task, the semantic priming effect was reflected as a distributional shift, with the size of the semantic priming effect constant throughout the RT distribution.

Building on the task-dependent notion introduced in Chapter 3, it was proposed that the different RT distribution patterns in the lexical decision and semantic categorization tasks indicated that the processes underlying the semantic priming effects in these two tasks were driven by different processes. The overadditive interaction pattern observed in the lexical decision task has been associated with the use of the retrospective semantic matching strategy (e.g., Balota et al., 2008; Thomas et al., 2012). From this perspective, the absence of a masked semantic priming effect in the lexical decision task could be explained: In order to assess the relationship between prime and target, the participant needs to be aware of the prime's identity. In contrast, the distributional shift pattern observed in the semantic categorization task has been proposed to reflect source confusion with the semantic features accumulated from the prime and target used together to make the category decision to the target (see Chapter 2). Importantly, the masked semantic priming effect was reflected in the same distributional shift pattern, indicating that masking the prime does not impact the occurrence of source confusion. From this perspective, the task-dependence of masked semantic priming effects demonstrated in Chapter 4, reflects the task-dependent process that are responsible for semantic priming effects in the lexical decision and the semantic categorization tasks.

Task-Dependent Processes

To summarize, in direct contradiction to the widely held view that semantic priming effects at short SOAs reflect an *automatic* spreading activation process, the results from Chapters 2, 3, and 4, demonstrated that the semantic priming effect is 1) modulated by RP at a short SOA in both the semantic categorization and lexical decision task, indicating that semantic priming is *not* "uncontrollable", and 2) is task-dependent when primes are masked, indicating that semantic priming does *not* "occur without conscious awareness" when the task is not semantic in nature. Moreover, RT distribution analyses demonstrated that semantic priming effects were reflected in different patterns in the semantic categorization and lexical decision tasks. These results are difficult to explain in terms of an automatic spreading activation process. Instead, in this thesis, I suggest that semantic priming effects at a short SOA reflect a task-dependent evidence accumulation process. In the next section, I will discuss how the prime is used to produce semantic priming effects in these different decision tasks.

Semantic Priming in Semantic Categorization: Evidence Accumulation and Source Confusion

In Chapter 2, an alternative account was proposed in which semantic priming effects in the semantic categorization task are explained in terms of evidence accumulation and source confusion, notions borrowed from the Bayesian Reader account of masked priming (Norris & Kinoshita, 2008) and the ROUSE (Responding Optimally to Unknown Sources of Evidence) model of short-term priming (Huber, Shiffrin, Lyle, & Ruys, 2001). According to the Bayesian Reader (Norris, 2006; 2009), in order to make a decision to the target, evidence has to be accumulated for a hypothesis that is dictated by the task, for example "the target is an animal" in the semantic categorization task or "the target is a word" in the lexical decision task. In the semantic categorization task, I assumed that the "evidence" consists of distributed semantic features such as <has four legs> and <has fur> that are diagnostic of an item's category membership (e.g., see Grondin, Lupker, & McRae, 2009; Rosch & Mervis, 1975; Smith, Shoben, & Rips, 1974, for support for this assumption). In line with the source confusion notion of the ROUSE model, it is assumed that evidence is accumulated from the prime as well as the target due to their close spatial and temporal proximity. To the extent that the accumulated semantic features from the prime are shared by the target (as would be the case when semantically related prime–target pairs are selected to have high semantic feature overlap; e.g., *hawk–EAGLE; sofa–COUCH*), the categorization decision to the target is facilitated, that is, a semantic priming effect is observed. Support for the view that the prime provides a head-start to the evidence accumulation process of the target was found in the RT distribution analysis: The semantic priming effect was reflected in an overall shift of the RT distribution, with the size of the semantic priming effect constant throughout the distribution. How then, is this process modulated, and the head-start RT distribution pattern, affected by the manipulation of RP and prime visibility?

Manipulating Relatedness Proportion

In Chapter 2, it was demonstrated that RP impacted on the size of the semantic priming effect in the semantic categorization task: In the high RP condition (.75 related trials), the semantic priming effect (58 ms) was more than five times greater than in the low RP condition (.25 related trials). It was proposed that this robust RP effect was driven by a prime filtering process akin to the early bottleneck suggested in bottleneck models of attention (e.g., Broadbent, 1958; Treisman, 1960). This prime filter, which is applied on the basis of perceptual cues that distinguish between the prime and the target (e.g., the prime is presented in lowercase letters, the target is presented in uppercase letters), modulates the number of semantic features contributed by the prime, hence the amount of source confusion. Consider the low RP condition, in which it is beneficial to reduce the prime's contribution as the semantic features from the prime are inconsistent with the decision required to the target on a high proportion of trials. In contrast, in the high RP condition, it is advantageous to combine the evidence from the prime with that from the target, as it is consistent with the decision required to the target on most trials. Remembering that source confusion is reflected as an overall shift of the RT distribution, the modulation of source confusion through this prime filtering process is reflected in a modulation of the distributional shift: The distributional shift is larger when RP is high compared to when RP is low.

Manipulating Prime Visibility

An important assumption of the proposed account of semantic priming—and one that is consistent with the ROUSE model (Huber et al., 2001)—is that conscious awareness of the prime is no prerequisite for source confusion to occur. That is, in any decision task, task-specific evidence is accumulated from any prime that is in close spatial and temporal proximity of the target. Masking the prime should therefore have little bearing on the semantic priming effect in the semantic categorization task. This notion was supported in Chapter 4, in which reliable semantic priming effects were obtained in the semantic categorization task, even when primes were masked.

Furthermore, the RT distribution analysis demonstrated that masked semantic priming effect was reflected in the same distributional shift pattern as the semantic priming effect obtained with unmasked primes, indicating that the effects were driven by the same head-start mechanism.

Semantic Priming in Lexical Decision: Retrospective Semantic Matching Strategy

In contrast to the semantic categorization task, in which the prime's semantic features are directly used to assist the categorization decision to the target, it is the retrospective assessment of the relationship between prime and target that is used to assist the decision ("is the target a word?") in the lexical decision task. In a typical lexical decision task, only the word targets are related to the primes, and the relatedness of prime and target (or lack thereof) is therefore indicative of the target's lexical status. The relatedness information is not available until after the target is presented, and is therefore used retrospectively to assist the decision to the target. Several recent studies have demonstrated that semantic priming effects, assumed to be driven by this retrospective semantic matching strategy, are reflected in the RT distribution as overadditive interactions, that is, the magnitude of the semantic priming effect is larger in the tail of the RT distribution (e.g., Balota et al., 2008; Thomas et al., 2012).

In Chapters 3 and 4, I suggested that in the lexical decision task, the decision required to the target need not be directly semantically driven. Instead, the decision can be based on multiple sources of information, including orthographic information (e.g., Norris, 2006), and semantic information is just one of the sources of information that is used to make a lexical decision. It was proposed that the retrospectively assessed semantic information is combined with other sources of information (e.g., orthographic, phonological) in a "compound cue" (Ratcliff & McKoon, 1988) to make a decision to the target. The strength of a compound cue—reflecting the "word-likeness" of the target—

represents the rate of evidence accumulation. Adding the retrospectively assessed relatedness information to the cue increases its strength, which is reflected in the RT distribution as an effect on the skew of the distribution, that is, an overadditive interaction pattern (e.g., Gomez, Perea, & Ratcliff, 2013; Pratte, Rouder, Morey, & Feng, 2010).

From the view that semantic priming effects obtained in the lexical decision task were driven by the retrospective assessment of the prime–target relatedness, the findings that semantic priming in the lexical decision was *not* "uncontrollable" (i.e., the robust RP effect found in Chapter 3) and did *not* "occur without conscious awareness" (i.e., the absence of the masked semantic priming effect found in Chapter 4) are readily explained, as follows.

Manipulating Relatedness Proportion

As Neely et al. (1989) pointed out, the use of the retrospective semantic matching strategy is tied to the nonword ratio (the proportion of nonword targets given an unrelated prime), which is typically confounded with RP; an increase in RP goes hand in hand with an increase in nonword ratio. As nonword ratio increases, the presence (or rather the absence) of a prime–target relationship becomes a more successful indicator of the target's lexical status. From the perspective that the retrospectively assessed prime–target relationship is used as one of the sources of information that is used to drive the word–nonword discrimination decision, an increase in nonword ratio could be seen as an increase in the strength of the compound cue. The RT distribution pattern observed in Chapter 3, in which the RP effect was reflected as an increase in the overadditive interaction—the large effect in the tail of the RT distribution was larger when RP was high relative to when RP was low—is readily interpretable as an increase in the rate of evidence accumulation as a function of an increase in the diagnostic value of the prime–target relatedness.

Manipulating Prime Visibility

The notion that semantic priming effects in the lexical decision task are driven by the retrospective assessment of the target's relationship to the prime, can explain why masking the prime eliminated the semantic priming effect in Chapter 4. In the masked priming paradigm (Forster & Davis, 1984), the target functions as a backward-mask to prevent conscious awareness of the prime's identity. However, this backward-masking of the prime may also preclude the use of the retrospective semantic matching strategy (e.g., De Groot, 1983). As was pointed out by Neely (1991), it seems unlikely that "a subject would try to adopt a strategy of finding a semantic relation between the target and an event, i.e., the masked prime, which the subject claims doesn't even exist" (p. 317). The assumption that awareness of the prime's identity is a prerequisite for retrospectively assessing the prime–target relationship explains the absence of the masked semantic priming effect observed in Chapter 4.

Implications and Future Directions

The proposed view of semantic priming in which semantic priming effects are not explained in terms of an automatic spreading activation process but instead in terms of task-dependent processes, invites some factors to consider for future work.

First and foremost, the way in which semantic priming effects are analysed should be reconsidered. Semantic priming effects are traditionally assessed on the basis of mean RT. However, manipulations that have similar effects on mean RTs may affect the pattern of RT distribution differently. "Moving beyond the mean" and analysing the whole RT distribution instead can provide a richer picture of the semantic priming effect that can reveal important information about the underlying mechanisms of an effect (Balota & Yap, 2011). Indeed, RT distribution analyses have provided invaluable information in this thesis, by revealing important task dissociations in how semantic priming effects are produced and modulated that would have not been discovered and further explored if I had relied on the mean RT only.

Explaining these task dissociations indicated that consideration of the type of task used, and more specifically the decision it requires to the target, is important. While the more traditional view, which explains semantic priming in terms of the automatic spread of semantic activation, suggests that the semantic priming effect "should not be modulated by differing task demands" (Neely, 1991, p. 298), the research presented in this thesis clearly demonstrated that the type of task plays an important role in semantic priming: It is the task that dictates the required decision to the target, and also the way in which the prime is used to assist this decision. Whereas the category decision in the semantic categorization task is based directly on the semantic features of the input, in the lexical decision task, the prime's semantics need not be the primary source of information used for making the decision. For lexical decision, I suggest that the retrospective assessment of the target's relationship to the prime, rather than the direct use of the prime's semantics, drives the semantic priming effect. These different uses of the prime's semantics drive the different RT distribution patterns of the semantic priming effect in the semantic categorization and lexical decision tasks.

Future work can build on, and extend, this task-dependent notion. In the present thesis, I investigated the effects of manipulating RP and prime visibility, and found that these manipulations modulated the semantic priming effect differently in the lexical decision and semantic categorization tasks, at the level of the RT distribution. The task-dependent modulation of the semantic priming effect by RP invites a comparison with other manipulations that have been crossed with semantic priming, for example stimulus quality. Stimulus quality (visually degrading the target, for example, by contrast reduction or superimposing a dynamic mask) has typically been found to interact with the semantic priming effect in lexical decision, with the semantic priming effect being greater when targets are visually degraded relative to when targets are clearly presented (e.g., Borowsky & Besner, 1993; Brown & Besner, 2002; Stolz & Neely, 1995; Yap, Balota, & Tan, 2013). Several recent studies demonstrated that this interaction is manifested in the shape of the RT distribution: While the semantic priming effect is reflected as a distributional shift for clear targets, the semantic priming effect increases in the tail of the RT distribution when targets are visually degraded (Balota et al., 2008, Experiment 5 and 7; Thomas et al., 2012; Yap, et al., 2013, Experiment 2). This pattern is similar to the effect of RP on the semantic priming effect found in the lexical decision task in Chapter 3. As with the RP manipulation, visually degrading the target has been suggested to increase "the reliance on the prime"—when it is difficult to make a decision to the target, the utility of the prime increases (e.g., Balota et al., 2008). The question arises as to whether a similar task dissociation (between the lexical decision task and the semantic categorization task) would be found at the level of RT distribution with the target degradation manipulation, as with the RP manipulation investigated in the present thesis. Specifically, if both the RP and target degradation manipulations "increase the reliance on the prime", would the same pattern of task dissociation in RT distribution be found with the target degradation manipulation? Exploring a potential task-dependence of the modulation of the semantic priming effect by target degradation and other factors could allow further insight into the workings of semantic priming.

Summary and Conclusion

In this thesis, I investigated the notion that semantic priming effects at short SOAs are driven by an automatic spreading activation process that is assumed to be “uncontrollable or involuntary” and to “occur without conscious awareness”. These assumptions predict that semantic priming effects should 1) not be impacted on by RP, 2) should be task-invariant, and 3) should be found with masked primes as well as unmasked primes. In direct contradiction to these assumptions, the research presented in this thesis demonstrated that semantic priming effects were modulated by RP in both the semantic categorization and the lexical decision task, and that masked semantic priming effects were task-dependent: Masking the prime eliminated the semantic priming effect in the lexical decision task but not in the semantic categorization task. Furthermore, RT distribution analyses demonstrated that semantic priming effects obtained in these two tasks were reflected in different patterns, indicating that the semantic priming effects were driven by different processes. These findings challenged the automatic spreading activation explanation of semantic priming effects at short SOAs. Instead, an alternative view in which semantic priming effects are explained in terms of task-dependent processes was proposed. The key assumption of this view—that the semantic priming effects reflect task-dependent use of the prime to assist the decision required to the target—provides a coherent explanation of the task-dependent RT distribution patterns of semantic priming effects and their modulation by RP, as well as the task-dependence of masked semantic priming effects.

References

Balota, D. A., & Yap, M. J. (2011). Moving beyond the mean in studies of mental chronometry: The power of response time distributional analyses. *Current Directions in Psychological Science, 20*, 160-166.

Balota, D. A., Yap, M. J., Cortese, M. J., & Watson, J. M. (2008). Beyond mean response latency: Response time distributional analysis of semantic priming. *Journal of Memory and Language, 59*, 495-523.

Borowsky, R., & Besner, D. (1993). Visual word recognition: A multistage activation model. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 19*, 813-840.

Broadbent, D. E. (1958). *Perception and communication*. New York: Oxford University Press.

Brown, M., & Besner, D. (2002). Semantic priming: On the role of awareness in visual word recognition in the absence of expectancy. *Consciousness and Cognition, 11*, 402-422.

Bueno, S., & Frenck-Mestre, C. (2008). The activation of semantic memory: Effects of prime exposure, prime-target relationship, and task demands. *Memory & Cognition, 36*, 882-898.

Collins, A. M., & Loftus, E. F. (1975). A spreading-activation theory of semantic processing. *Psychological Review, 82*, 407-428.

De Groot, A. M. B. (1983). The range of automatic spreading activation in word priming. *Journal of Verbal Learning and Verbal Behavior, 22*, 417-436.

De Groot, A. M. B. (1984). Primed lexical decision: Combined effects of the proportion of related prime–target pairs and the stimulus-onset asynchrony of prime and target. *The Quarterly Journal of Experimental Psychology Section A, 36*, 253-280.

Forster, K. I., & Davis, C. (1984). Repetition priming and frequency attenuation in lexical access. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 10*, 680-698.

Gomez, P., Perea, M., & Ratcliff, R. (2013). A diffusion model account of masked vs. unmasked priming: Are they qualitatively different? *Journal of Experimental Psychology: Human Perception and Performance*, *39,* 1731-1740.

Grondin, R., Lupker, S. J., & McRae, K. (2009). Shared features dominate semantic richness effects for concrete concepts. *Journal of Memory and Language, 60*, 1-19.

Huber, D. E., Shiffrin, R. M., Lyle, K. B., & Ruys, K. I. (2001). Perception and preference in short-term word priming. *Psychological Review, 108*, 149-182.

Neely, J. H. (1991). Semantic priming effects in visual word recognition: A selective review of current findings and theories. In D. Besner & G.W. Humphreys (Eds.), *Basic processes in reading: Visual word recognition* (pp. 264-336). Hillsdale, NJ: Erlbaum.

Neely, J. H., Keefe, D. E., & Ross, K. L. (1989). Semantic priming in the lexical decision task: Roles of prospective prime-generated expectancies and retrospective semantic matching. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 15*, 1003-1019.

Norris, D. (2006). The Bayesian reader: Explaining word recognition as an optimal Bayesian decision process. *Psychological Review, 113,* 327-357.

Norris, D. (2009). Putting it all together: A unified account of word recognition and reaction-time distributions. *Psychological Review, 116,* 207-219.

Norris, D., & Kinoshita, S. (2008). Perception as evidence accumulation and Bayesian inference: Insights from masked priming. *Journal of Experimental Psychology: General, 137*, 434-455.

Perea, M., & Gotor, A. (1997). Associative and semantic priming effects occur at very short stimulus-onset asynchronies in lexical decision and naming. *Cognition, 62*, 223-240.

Posner, M. I., & Snyder, C. R. R. (1975). Attention and cognitive control. In R.L. Solso (Ed.), *Information processing and cognition: The Loyala symposium* (pp. 55-85). Hillsdale, NJ: Lawrence Erlbaum Associates, Inc.

Pratte, M. S., Rouder, J. N., Morey, R. D., & Feng, C. (2010). Exploring the differences in distributional properties between Stroop and Simon effects using delta plots. *Attention, Perception & Psychophysics, 72*, 2013-2025.

Ratcliff, R., & McKoon, G. (1988). A retrieval theory of priming in memory. *Psychological Review, 95*, 385-408.

Rosch, E., & Mervis, C. B. (1975). Family resemblances: Studies in the internal structure of categories. *Cognitive Psychology, 7*, 573-605.

Smith, E. E., Shoben, E. J., & Rips, L. J. (1974). Structure and process in semantic memory: A featural model for semantic decisions. *Psychological Review, 81*, 214-241.

Stolz, J. A., & Neely, J. H. (1995). When target degradation does and does not enhance semantic context effects in word recognition. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 21*, 596-611.

Thomas, M. A., Neely, J. H. & O'Connor, P. (2012). When word identification gets tough, retrospective processing comes to the rescue. *Journal of Memory and Language, 66*, 623-643.

Treisman, A. (1960). Contextual cues in selective listening. *Quarterly Journal of Experimental Psychology, 12*, 242-248

Tweedy, J., Lapinski, R., & Schvaneveldt, R. (1977). Semantic-context effects on word recognition: Influence of varying the proportion of items presented in an appropriate context. *Memory & Cognition, 5*, 84-89.

Yap, M. J., Balota, D. A., & Tan, S.E. (2013). Additive and interactive effects in semantic priming: Isolating lexical and decision processes in the lexical decision task. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 39*, 140-158.

Appendices

Appendix A

Stimuli used in the Semantic Categorization Task

Related prime–target pairs (both animal and nonanimal—man-made—items) were selected on the basis of high semantic similarity according to the McRae, Cree, Seidenberg, and McNorgan's (2005) semantic feature production norms. In addition, the related prime–target pairs were selected to be highly semantically similar according to the Latent Semantic Analysis norms (LSA, Landauer, McNamara, Dennis, & Kintsch, 2007). Targets were paired with category-incongruent pairs, matched closely on length, in the semantically unrelated condition.

The critical animal targets are listed in Table A1, the critical nonanimal targets in Table A2. The filler animal items are listed in Table A3, the filler nonanimal items in Table A4.

Table A1

Overview of the critical animal items and their properties.

Items			Length			Frequency[a]			Similarity[b]	
	Prime			Prime			Prime			
Target	Related	Unrelated	Target	Related	Unrelated	Target	Related	Unrelated	McRae	LSA
CHIMPANZEE	gorilla	microscope	10	7	10	1.60	2.20	2.02	0.42	0.70
SALAMANDER	iguana	chandelier	10	6	10	0.90	1.30	1.74	0.52	0.35
BUTTERFLY	moth	cathedral	9	4	9	2.27	1.85	2.00	0.63	0.69
CROCODILE	alligator	accordion	9	9	9	1.85	2.10	1.67	0.82	0.48
COCKROACH	beetle	corkscrew	9	6	9	2.05	1.76	1.65	0.72	0.54
BLACKBIRD	falcon	microwave	9	6	9	1.32	1.74	2.22	0.82	0.27
KANGAROO	wallaby	necklace	8	7	8	1.78	0.85	2.45	-	0.55
PHEASANT	peacock	trailer	8	7	7	1.49	1.76	2.47	0.67	0.22
STALLION	mare	scissors	8	4	8	1.98	1.93	2.32	-	0.72
TORTOISE	turtle	football	8	6	8	1.45	2.42	2.91	0.81	0.26
DOLPHIN	whale	guitar	7	5	6	1.86	2.37	2.53	0.44	0.64
BUFFALO	bison	trumpet	7	5	7	2.40	1.04	2.00	0.83	0.69
LEOPARD	cheetah	shelves	7	7	7	1.93	1.54	2.05	0.41	0.19
PELICAN	stork	fridge	7	5	6	1.59	1.75	2.59	0.64	0.34
SARDINE	tuna	cage	7	4	4	1.49	2.39	2.75	0.78	0.20
OCTOPUS	squid	sweater	7	5	7	1.81	1.88	2.67	0.68	0.56
SPARROW	robin	cabinet	7	5	7	1.77	2.45	2.50	0.60	0.23
OSTRICH	emu	balloon	7	3	7	1.53	1.04	2.42	0.68	-
PANTHER	cougar	buckle	7	6	6	1.67	1.54	2.33	0.59	0.34
ROOSTER	chicken	lantern	7	7	7	2.01	3.20	1.85	0.55	0.24
RACCOON	skunk	church	7	5	6	1.71	2.03	3.13	0.50	0.50
LOBSTER	crab	ball	7	4	4	2.31	2.28	3.32	0.76	0.50
COYOTE	hyena	ashtray	6	5	7	2.03	1.58	2.07	0.51	0.12
WALRUS	seal	mirror	6	4	6	1.61	2.67	2.94	0.54	0.37

Table A1 (*continued*)
Overview of the critical animal items and their properties.

Items			Length			Frequency[a]			Similarity[b]	
	Prime			Prime			Prime			
Target	Related	Unrelated	Target	Related	Unrelated	Target	Related	Unrelated	McRae	LSA
SALMON	trout	crown	6	5	5	2.27	2.05	2.56	0.89	0.74
PIGEON	dove	toilet	6	4	6	2.26	2.13	2.98	0.68	0.30
RABBIT	hare	tractor	6	4	7	2.65	1.90	2.03	0.43	0.41
SHEEP	lamb	ruler	5	4	5	2.59	2.51	2.14	0.74	0.53
GOOSE	duck	chain	5	4	5	2.58	2.85	2.87	0.63	0.49
EAGLE	hawk	chair	5	4	5	2.45	2.40	3.19	0.82	0.72
DINGO	dog	key	5	3	3	1.32	3.48	3.34	-	0.07
MOUSE	rat	rifle	5	3	5	2.60	2.97	2.59	0.58	0.54
TIGER	lion	drill	5	4	5	2.65	2.52	2.67	0.61	0.68
MOOSE	deer	razor	5	4	5	2.10	2.39	2.40	0.73	0.57
OTTER	beaver	flute	5	6	5	1.45	2.11	1.86	0.56	0.39
RAVEN	crow	piano	5	4	5	1.78	2.12	2.78	0.76	0.46
TOAD	frog	door	4	4	4	2.12	3.23	3.72	0.72	0.87
WASP	bee	doll	4	3	4	1.64	2.40	2.81	-	0.57
PONY	horse	fence	4	5	5	2.42	3.20	2.74	0.59	0.79
COW	ox	bed	3	2	3	2.86	2.26	3.61	0.53	0.38

[a]Frequency was indexed by the log subtitle contextual diversity value (lgSUBTLCD; the log of the SUBTLEX contextual diversity value) which corresponds to the percentages of films containing the word. Brysbaert and New (2009) argued this is the best value to use when matching words on word frequency.
[b]Similarity was indexed by two values: 1) McRae, Cree, Seidenberg, and McNorgan's (2005) semantic feature production norms, in which similarity between two concepts is represented by the cosine, "the dot product between two concept vectors, divided by the product of their lengths" (p. 553). 2) Latent Semantic Analysis norms (LSA, Landauer, McNamara, Dennis, & Kintsch, 2007), in which similarity is represented by the cosine between two word vectors.

Table A2

Overview of the critical nonanimal (man-made) items and their properties.

Items			Length			Frequency[a]			Similarity[b]	
	Prime			Prime			Prime			
Target	Related	Unrelated	Target	Related	Unrelated	Target	Related	Unrelated	McRae	LSA
HELICOPTER	airplane	rattlesnake	10	8	11	2.65	2.55	1.76	0.12	0.62
APARTMENT	bungalow	woodpecker	9	8	10	3.25	1.69	1.36	0.33	0.23
SAXOPHONE	trumpet	mackerel	9	7	8	1.65	2.00	1.94	0.60	0.55
ESCALATOR	elevator	penguin	9	8	7	1.69	2.83	1.79	0.42	0.28
BASEMENT	cellar	flamingo	8	6	8	2.83	2.37	1.60	0.52	0.58
BRACELET	necklace	catfish	8	8	7	2.29	2.45	1.72	0.62	0.42
KEYBOARD	piano	cougar	8	5	6	1.83	2.78	1.54	0.72	0.13
CLARINET	flute	scorpion	8	5	8	1.57	1.86	1.75	0.80	0.57
CUPBOARD	cabinet	platypus	8	7	8	2.00	2.50	0.60	0.84	0.14
TROUSERS	pants	chicken	8	5	7	2.27	3.25	3.20	0.76	0.71
CURTAINS	drapes	sealion	8	6	7	2.37	2.03	-	0.93	0.43
SCOOTER	bike	wallaby	7	4	7	1.90	2.76	0.85	0.57	0.28
FREEZER	fridge	gorilla	7	6	7	2.33	2.59	2.20	0.60	0.20
HARPOON	spear	cheetah	7	5	7	1.51	2.04	1.54	0.62	0.17
MITTENS	gloves	peacock	7	6	7	1.59	2.67	1.76	0.68	0.36
CUSHION	pillow	camel	7	6	5	2.00	2.66	2.14	0.68	0.26
BLENDER	mixer	seagull	7	5	7	1.78	1.70	1.54	0.78	0.21
COTTAGE	hut	iguana	7	3	6	2.22	2.33	1.30	0.71	0.54
SLEIGH	sled	hyena	6	4	5	1.86	1.80	1.58	0.45	0.40
KETTLE	pot	possum	6	3	6	2.08	2.88	1.74	0.28	0.50
BOTTLE	jar	toucan	6	3	6	3.19	2.47	0.60	0.73	0.60
PISTOL	rifle	beetle	6	5	6	2.51	2.59	1.76	0.70	0.44
BUREAU	desk	wombat	6	4	6	2.55	3.15	0.95	0.45	0.15

Table A2 (*continued*)
Overview of the critical nonanimal (man-made) items and their properties.

Items			Length			Frequency[a]			Similarity[b]	
	Prime			Prime			Prime			
Target	Related	Unrelated	Target	Related	Unrelated	Target	Related	Unrelated	McRae	LSA
CHAPEL	church	falcon	6	6	6	2.24	3.13	1.74	0.65	0.42
SHOVEL	spade	turtle	6	5	6	2.40	1.76	2.42	0.52	0.24
BOOTS	shoes	whale	5	5	5	2.78	3.31	2.37	0.62	0.64
SKIRT	dress	trout	5	5	5	2.59	3.34	2.05	0.71	0.73
SWORD	knife	bison	5	5	5	2.67	3.10	1.04	0.68	0.23
BENCH	chair	stork	5	5	5	2.54	3.19	1.75	0.51	0.39
BANJO	guitar	duck	5	6	4	1.71	2.53	2.85	0.79	0.38
SCARF	shawl	deer	5	5	4	2.22	1.66	2.39	0.46	0.34
SPOON	fork	leech	5	4	5	2.43	2.50	1.71	0.55	0.48
YACHT	ship	bunny	5	4	5	2.30	3.07	2.53	0.44	0.31
WAGON	cart	ibis	5	4	4	2.67	2.51	0.70	0.74	0.46
STOVE	oven	horse	5	4	5	2.45	2.52	3.20	0.68	0.57
TRUCK	van	robin	5	3	5	3.19	2.96	2.45	0.70	0.25
COUCH	sofa	squid	5	4	5	2.90	2.36	1.88	0.88	0.71
BOWL	dish	swan	4	4	4	2.83	2.65	2.03	0.65	0.63
GATE	door	bear	4	4	4	2.96	3.72	3.18	0.82	0.47
BUS	car	dog	3	3	3	3.19	3.71	3.48	0.56	0.22

[a]Frequency was indexed by lgSUBTLCD (Brysbaert & New, 2009).
[b]Similarity was indexed by 1) McRae et al.'s (2005) semantic feature production norms, and 2) LSA (Landauer et al., 2007).

Table A3
Overview of the filler animal items and their properties.

Item				Length				Frequency[a]				Similarity[b]		
	Prime in RP				Prime in RP				Prime in RP			LSA in RP		
Target	.25	.50	.75	Target	.25	.50	.75	Target	.25	.50	.75	.25	.50	.75
CATERPILLAR	ladle	worm	worm	11	5	4	4	1.54	1.45	2.43	2.43	0.02	0.24	0.24
KOOKABURRA	computer	trolley	magpie	10	8	7	6	0.30	3.09	1.68	1.11	-0.02	0.07	0.10
RHINOCEROS	catapult	elephant	elephant	10	8	8	8	1.48	1.36	2.50	2.50	0.00	0.65	0.65
PORCUPINE	house	echidna	echidna	9	5	7	7	1.36	3.78	0.60	0.60	0.05	-0.01	-0.01
TARANTULA	diploma	spider	spider	9	7	6	6	1.45	2.02	2.37	2.37	-0.02	0.40	0.40
DALMATIAN	cannon	cannon	labrador	9	6	6	8	1.30	2.41	2.41	1.26	-0.05	-0.05	0.13
JELLYFISH	mallet	bluebottle	bluebottle	9	6	10	10	1.61	1.53	0.60	0.60	0.01	0.02	0.02
CHIPMUNK	shower	squirrel	squirrel	8	6	8	8	1.48	3.11	2.22	2.22	0.03	0.47	0.47
MOSQUITO	violin	housefly	housefly	8	6	8	8	1.88	2.09	0.90	0.90	0.04	0.06	0.06
ANTELOPE	basket	gazelle	gazelle	8	6	7	7	1.53	2.63	1.54	1.54	0.08	0.18	0.18
GOLDFISH	canoe	guppy	guppy	8	5	5	5	2.00	1.89	1.18	1.18	0.02	0.22	0.22
DUCKLING	trolley	chick	chick	8	7	5	5	1.38	1.68	2.87	2.87	0.02	0.38	0.38
PARAKEET	bridge	bridge	budgie	8	6	6	6	1.60	3.02	3.02	0.48	0.02	0.02	0.11
LEMMING	closet	hamster	hamster	7	6	7	7	0.85	2.95	1.76	1.76	-0.03	-0.02	-0.02
VULTURE	shirt	shirt	buzzard	7	5	5	7	1.81	3.15	3.15	1.90	0.04	0.04	0.02
GIRAFFE	train	train	zebra	7	5	5	5	1.76	3.25	3.25	1.77	0.07	0.07	0.68
TERMITE	coat	coat	ant	7	4	4	3	1.40	3.10	3.10	2.05	0.01	0.01	0.40
CANARY	watch	watch	finch	6	5	5	5	1.99	3.77	3.77	1.81	0.08	0.08	0.16
DONKEY	plate	mule	mule	6	5	4	4	2.21	2.97	2.33	2.33	0.00	0.37	0.37
PYTHON	motor	motor	cobra	6	5	5	5	1.62	2.67	2.67	1.79	0.05	0.05	0.23
ALPACA	pen	pen	llama	6	4	3	5	0.95	2.72	2.91	1.45	0.06	0.06	0.26
LIZARD	cup	cup	gecko	6	3	3	5	2.06	3.20	3.20	1.20	0.05	0.05	-

Table A3 (*continued*)
Overview of the filler animal items and their properties.

Item				Length				Frequency[a]				Similarity[b]		
	Prime in RP				Prime in RP				Prime in RP			LSA in RP		
Target	.25	.50	.75	Target	.25	.50	.75	Target	.25	.50	.75	.25	.50	.75
PUPPY	hat	kitten	kitten	6	3	6	6	2.58	3.24	2.20	2.20	0.07	0.43	0.43
MONKEY	palace	palace	ape	6	6	6	3	2.89	2.64	2.64	2.24	0.12	0.12	0.39
FERRET	radio	radio	weasel	6	5	5	6	1.68	3.21	3.21	2.27	0.02	0.02	0.34
SHRIMP	axe	prawn	prawn	6	3	5	5	2.39	2.18	1.18	1.18	0.03	-	-
TURKEY	book	book	hen	6	4	4	3	2.76	3.51	3.51	2.03	0.02	0.02	0.09
INSECT	robe	bug	bug	6	4	3	3	2.04	2.45	2.77	2.77	0.01	0.35	0.35
PARROT	towel	lorikeet	lorikeet	6	5	8	8	1.98	2.72	-	-	0.02	-	-
JAGUAR	bomb	lynx	lynx	6	4	4	4	1.81	2.97	0.30	0.30	0.06	0.14	0.14
SNAIL	purse	purse	slug	5	5	5	4	1.74	2.83	2.83	2.28	0.06	0.06	0.23
SHARK	lamp	lamp	orca	5	4	4	4	2.41	2.59	2.59	1.23	0.04	0.04	-
STEER	jail	bull	bull	5	4	4	4	2.38	3.23	2.82	2.82	0.08	0.25	0.25
KOALA	hook	hook	panda	5	4	4	5	1.18	3.11	3.11	1.58	-0.06	-0.06	0.23
SNAKE	pin	taipan	taipan	5	3	6	6	2.72	2.74	0.60	0.60	0.08	-	-
WOLF	tap	fox	fox	4	3	3	3	2.58	2.68	2.61	2.61	0.03	0.59	0.59
FOAL	gun	gun	colt	4	3	3	4	1.11	3.47	3.47	1.92	0.08	0.08	0.58
GOAT	mop	mop	ram	4	3	3	3	2.53	2.18	2.18	2.30	0.09	0.09	0.28
EEL	shed	shed	cod	3	4	4	3	1.72	2.62	2.62	1.85	0.13	0.13	0.34
PIG	cigar	cigar	hog	3	5	5	3	3.02	2.72	2.59	2.29	0.08	0.08	0.45

[a]Frequency was indexed by lgSUBTLCD (Brysbaert & New, 2009).
[b]Similarity was indexed by 1) McRae et al.'s (2005) semantic feature production norms, and 2) LSA (Landauer et al., 2007).

Table A4
Overview of the filler nonanimal (man-made) items and their properties.

Item				Length				Frequency[a]				Similarity[b]		
	Prime in RP				Prime in RP				Prime in RP			LSA in RP		
Target	.25	.50	.75	Target	.25	.50	.75	Target	.25	.50	.75	.25	.50	.75
CERTIFICATE	bluebottle	diploma	diploma	11	10	7	7	2.47	0.60	2.02	2.02	0.02	0.36	0.36
TYPEWRITER	elephant	computer	computer	10	8	8	8	1.97	2.50	3.09	3.09	0.01	0.36	0.36
CIGARETTE	labrador	labrador	cigar	9	8	8	6	2.94	1.26	1.26	2.59	0.02	0.02	0.26
SLINGSHOT	housefly	catapult	catapult	9	8	8	8	1.66	0.90	1.36	1.36	0.07	0.02	0.02
BUILDING	gazelle	house	house	8	7	5	5	3.38	1.54	3.78	3.78	-0.01	0.20	0.20
SUITCASE	echidna	panda	trolley	8	7	5	7	2.57	0.60	1.58	1.68	0.03	0.05	0.21
MAGAZINE	squirrel	buzzard	book	8	8	7	4	2.93	2.22	1.90	3.51	-0.03	0.02	0.29
BATHTUB	lorikeet	shower	shower	7	8	6	6	2.35	1.76	3.11	3.11	-	0.35	0.35
SPATULA	buzzard	ladle	ladle	7	7	5	5	1.51	1.90	1.45	1.45	0.05	0.11	0.11
BAZOOKA	llama	llama	cannon	7	5	5	6	1.54	1.45	1.45	2.41	0.04	0.04	0.28
DRESSER	bull	closet	closet	7	4	6	6	2.20	2.82	2.95	2.95	0.00	0.48	0.48
HATCHET	budgie	axe	axe	7	6	3	3	1.86	0.48	2.18	2.18	0.02	0.34	0.34
GRENADE	lynx	bomb	bomb	7	4	4	4	2.19	0.30	2.97	2.97	0.05	0.09	0.09
WEAPON	magpie	magpie	gun	6	6	6	3	3.09	1.11	1.11	3.47	0.01	0.01	0.42
NAPKIN	colt	towel	towel	6	4	5	5	2.14	1.92	2.72	2.72	0.01	0.25	0.25
PRISON	cobra	jail	jail	6	5	4	4	3.18	1.79	3.23	3.23	0.08	0.71	0.71
PENCIL	slug	colt	pen	6	4	4	4	2.59	2.28	1.92	2.91	0.30	0.03	0.42
HAMMER	finch	mallet	mallet	6	5	6	6	2.60	1.81	1.53	1.53	0.07	0.51	0.51
ANCHOR	weasel	weasel	hook	6	6	6	4	2.28	2.27	2.27	3.11	0.05	0.05	0.24
SAUCER	chick	plate	plate	6	5	5	5	1.86	2.87	2.97	2.97	0.06	0.09	0.09
TUNNEL	prawn	slug	bridge	6	5	4	6	2.65	1.18	2.28	3.02	-	0.08	0.27
ENGINE	kitten	ant	motor	6	6	3	5	2.91	2.20	2.05	2.67	-0.01	0.01	0.42

Table A4 (*continued*)
Overview of the filler nonanimal (man-made) items and their properties.

	Item			Length				Frequency[a]				Similarity[b]		
	Prime in RP				Prime in RP				Prime in RP			LSA in RP		
Target	.25	.50	.75	Target	.25	.50	.75	Target	.25	.50	.75	.25	.50	.75
BUCKET	panda	basket	basket	6	5	6	6	2.59	1.58	2.63	2.63	0.00	0.30	0.30
CASTLE	hamster	finch	palace	6	7	5	6	2.58	1.76	1.81	2.64	0.05	0.07	0.54
WALLET	orca	orca	purse	6	4	4	5	2.84	1.23	1.23	2.83	-	-	0.40
CANDLE	gecko	gecko	lamp	6	5	5	4	2.47	1.20	1.20	2.59	-	-	0.51
BLOUSE	taipan	cod	shirt	6	6	3	5	2.27	0.60	1.85	3.15	-	0.01	0.64
STEREO	zebra	zebra	radio	6	5	5	5	2.34	1.77	1.77	3.21	0.01	0.01	0.17
JACKET	guppy	cobra	coat	6	5	5	4	2.99	1.18	1.79	3.10	0.02	0.00	0.60
SUBWAY	worm	budgie	train	6	4	6	5	2.53	2.43	0.48	3.25	0.00	-0.02	0.48
CELLO	hen	violin	violin	5	3	6	6	1.61	2.03	2.09	2.09	0.06	0.39	0.39
BROOM	ram	ram	mop	5	3	3	3	2.26	2.30	2.30	2.18	0.04	0.04	0.21
KAYAK	mule	canoe	canoe	5	4	5	5	1.08	2.33	1.89	1.89	0.03	0.47	0.47
CLOCK	hog	hog	watch	5	3	3	5	3.21	2.29	2.29	3.77	-0.01	-0.01	0.26
CLOAK	bug	robe	robe	5	3	4	4	1.97	2.77	2.45	2.45	0.00	0.54	0.54
TACK	ant	pin	pin	4	3	3	3	1.87	2.05	2.74	2.74	0.06	0.19	0.19
BARN	ape	ape	shed	4	3	3	4	2.60	2.24	2.24	2.62	0.02	0.02	0.63
SINK	spider	tap	tap	4	6	3	3	2.81	2.37	2.68	2.68	0.05	0.24	0.24
CAP	cod	hat	hat	3	3	3	3	2.79	1.85	3.24	3.24	0.05	0.52	0.52
MUG	fox	hen	cup	3	3	3	3	2.42	2.61	2.03	3.20	-0.01	0.02	0.48

[a]Frequency was indexed by lgSUBTLCD (Brysbaert & New, 2009).
[b]Similarity was indexed by 1) McRae et al.'s (2005) semantic feature production norms, and 2) LSA (Landauer et al., 2007).

Appendix B

Stimuli used in the Lexical Decision Task

The related prime–target pairs used in the lexical decision task were identical to the ones used in the semantic categorization task (see Appendix A). To create the semantically unrelated prime–target pairs, the targets were repaired with category-incongruent primes. The nonword targets were selected from the English Lexicon Project (ELP) Database (Balota, et al., 2007, available at http://elexicon.wustl.edu/).

The critical word targets are listed in Table B1, the nonword targets that were matched to the critical word targets in Table B2. The filler word items are listed in Table B3, the filler nonword items that were matched to the filler word items in Table B4.

Table B1

Overview of the critical word items and their properties.

Item			Length			Frequency[a]			Similarity[b]		
	Prime			Prime			Prime				Ortho_N[c]
Target	Related	Unrelated	Target	Related	Unrelated	Target	Related	Unrelated	McRae	LSA	Target
CHIMPANZEE	gorilla	elevator	10	7	8	1.60	2.20	2.83	0.42	0.70	0
SALAMANDER	iguana	airplane	10	6	8	0.90	1.30	2.55	0.52	0.35	0
HELICOPTER	airplane	iguana	10	8	6	2.65	2.55	1.30	0.12	0.62	0
BUTTERFLY	moth	cabinet	9	4	7	2.27	1.85	2.50	0.63	0.69	0
COCKROACH	beetle	pants	9	6	5	2.05	1.76	3.25	0.72	0.54	0
ESCALATOR	elevator	moth	9	8	4	1.69	2.83	1.85	0.42	0.28	0
CROCODILE	alligator	bungalow	9	9	8	1.85	2.10	1.69	0.82	0.48	0
BLACKBIRD	falcon	necklace	9	6	8	1.32	1.74	2.45	0.82	0.27	0
APARTMENT	bungalow	mare	9	8	4	3.25	1.69	1.93	0.33	0.23	0
SAXOPHONE	trumpet	turtle	9	7	6	1.65	2.00	2.42	0.60	0.55	0
KANGAROO	wallaby	flute	8	7	5	1.78	0.85	1.86	-	0.55	0
PHEASANT	peacock	drapes	8	7	6	1.49	1.76	2.03	0.67	0.22	1
KEYBOARD	piano	cheetah	8	5	7	1.83	2.78	1.54	0.72	0.13	0
CLARINET	flute	wallaby	8	5	7	1.57	1.86	0.85	0.80	0.57	0
CUPBOARD	cabinet	peacock	8	7	7	2.00	2.50	1.76	0.84	0.14	0
TROUSERS	pants	beetle	8	5	6	2.27	3.25	1.76	0.76	0.71	0
CURTAINS	drapes	gorilla	8	6	7	2.37	2.03	2.20	0.93	0.43	0
STALLION	mare	trumpet	8	4	7	1.98	1.93	2.00	-	0.72	1
TORTOISE	turtle	cellar	8	6	6	1.45	2.42	2.37	0.81	0.26	0
BASEMENT	cellar	chicken	8	6	7	2.83	2.37	3.20	0.52	0.58	2
BRACELET	necklace	alligator	8	8	9	2.29	2.45	2.10	0.62	0.42	2
DOLPHIN	whale	pot	7	5	3	1.86	2.37	2.88	0.44	0.64	0

Table B1(*continued*)
Overview of the critical word items and their properties.

	Item		Length			Frequency[a]			Similarity[b]		Ortho_N[c]
	Prime			Prime			Prime				
Target	Related	Unrelated	Target	Related	Unrelated	Target	Related	Unrelated	McRae	LSA	Target
BUFFALO	bison	spade	7	5	5	2.40	1.04	1.76	0.83	0.69	0
LEOPARD	cheetah	mixer	7	7	5	1.93	1.54	1.70	0.41	0.19	2
PELICAN	stork	hut	7	5	3	1.59	1.75	2.33	0.64	0.34	0
SARDINE	tuna	piano	7	4	5	1.49	2.39	2.78	0.78	0.20	0
BLENDER	mixer	stork	7	5	5	1.78	1.70	1.75	0.78	0.21	3
COTTAGE	hut	bison	7	3	5	2.22	2.33	1.04	0.71	0.54	0
OCTOPUS	squid	desk	7	5	4	1.81	1.88	3.15	0.68	0.56	0
SPARROW	robin	bike	7	5	4	1.77	2.45	2.76	0.60	0.23	0
OSTRICH	emu	sled	7	3	4	1.53	1.04	1.80	0.68	-	0
PANTHER	cougar	fridge	7	6	6	1.67	1.54	2.59	0.59	0.34	0
ROOSTER	chicken	spear	7	7	5	2.01	3.20	2.04	0.55	0.24	1
RACCOON	skunk	gloves	7	5	6	1.71	2.03	2.67	0.50	0.50	0
LOBSTER	crab	pillow	7	4	6	2.31	2.28	2.66	0.76	0.50	1
SCOOTER	bike	lion	7	4	4	1.90	2.76	2.52	0.57	0.28	2
FREEZER	fridge	skunk	7	6	5	2.33	2.59	2.03	0.60	0.20	1
HARPOON	spear	cougar	7	5	6	1.51	2.04	1.54	0.62	0.17	0
MITTENS	gloves	crab	7	6	4	1.59	2.67	2.28	0.68	0.36	1
CUSHION	pillow	falcon	7	6	6	2.00	2.66	1.74	0.68	0.26	0
COYOTE	hyena	sofa	6	5	4	2.03	1.58	2.36	0.51	0.12	0
WALRUS	seal	church	6	4	6	1.61	2.67	3.13	0.54	0.37	0
SALMON	trout	rifle	6	5	5	2.27	2.05	2.59	0.89	0.74	1
PIGEON	dove	jar	6	4	3	2.26	2.13	2.47	0.68	0.30	0
BOTTLE	jar	tuna	6	3	4	3.19	2.47	2.39	0.73	0.60	2

Table B1(*continued*)
Overview of the critical word items and their properties.

Item			Length			Frequency[a]			Similarity[b]		
	Prime			Prime			Prime				Ortho_N[c]
Target	Related	Unrelated	Target	Related	Unrelated	Target	Related	Unrelated	McRae	LSA	Target
PISTOL	rifle	seal	6	5	4	2.51	2.59	2.67	0.70	0.44	2
KETTLE	pot	dove	6	3	4	2.08	2.88	2.13	0.28	0.50	3
CHAPEL	church	trout	6	6	5	2.24	3.13	2.05	0.65	0.42	0
SHOVEL	spade	whale	6	5	5	2.40	1.76	2.37	0.52	0.24	1
RABBIT	hare	guitar	6	4	6	2.65	1.90	2.53	0.43	0.41	0
SLEIGH	sled	beaver	6	4	6	1.86	1.80	2.11	0.45	0.40	0
BUREAU	desk	robin	6	4	5	2.55	3.15	2.45	0.45	0.15	0
SHEEP	lamb	oven	5	4	4	2.59	2.51	2.52	0.74	0.53	7
GOOSE	duck	shawl	5	4	5	2.58	2.85	1.66	0.63	0.49	3
EAGLE	hawk	cart	5	4	4	2.45	2.40	2.51	0.82	0.72	0
DINGO	dog	van	5	3	3	1.32	3.48	2.96	-	0.07	3
SCARF	shawl	frog	5	5	4	2.22	1.66	3.23	0.46	0.34	3
SPOON	fork	dog	5	4	3	2.43	2.50	3.48	0.55	0.48	4
YACHT	ship	lamb	5	4	4	2.30	3.07	2.51	0.44	0.31	0
WAGON	cart	duck	5	4	4	2.67	2.51	2.85	0.74	0.46	0
STOVE	oven	hawk	5	4	4	2.45	2.52	2.40	0.68	0.57	7
TRUCK	van	bee	5	3	3	3.19	2.96	2.40	0.70	0.25	4
COUCH	sofa	hyena	5	4	5	2.90	2.36	1.58	0.88	0.71	6
MOUSE	rat	car	5	3	3	2.60	2.97	3.71	0.58	0.54	7
TIGER	lion	door	5	4	4	2.65	2.52	3.72	0.61	0.68	4
MOOSE	deer	shoes	5	4	5	2.10	2.39	3.31	0.73	0.57	6
HORSE	pony	dress	5	4	5	3.20	2.42	3.34	0.59	0.79	6
OTTER	beaver	chair	5	6	5	1.45	2.11	3.19	0.56	0.39	3

Table B1(*continued*)
Overview of the critical word items and their properties.

Item			Length			Frequency[a]			Similarity[b]		Ortho_N[c]
	Prime			Prime			Prime				
Target	Related	Unrelated	Target	Related	Unrelated	Target	Related	Unrelated	McRae	LSA	Target
RAVEN	crow	knife	5	4	5	1.78	2.12	3.10	0.76	0.46	2
BOOTS	shoes	deer	5	5	4	2.78	3.31	2.39	0.62	0.64	10
SKIRT	dress	pony	5	5	4	2.59	3.34	2.42	0.71	0.73	1
SWORD	knife	crow	5	5	4	2.67	3.10	2.12	0.68	0.23	2
BENCH	chair	squid	5	5	5	2.54	3.19	1.88	0.51	0.39	5
BANJO	guitar	hare	5	6	4	1.71	2.53	1.90	0.79	0.38	0
TOAD	frog	fork	4	4	4	2.12	3.23	2.50	0.72	0.87	5
WASP	bee	ship	4	3	4	1.64	2.40	3.07	-	0.57	5
BOWL	dish	emu	4	4	3	2.83	2.65	1.04	0.65	0.63	9
GATE	door	rat	4	4	3	2.96	3.72	2.97	0.82	0.47	16
COW	ox	dish	3	2	4	2.86	2.26	2.65	0.53	0.38	18
BUS	car	ox	3	3	2	3.19	3.71	2.26	0.56	0.22	8

[a]Frequency was indexed by the log subtitle contextual diversity value (lgSUBTLCD; the log of the SUBTLEX contextual diversity value) which corresponds to the percentages of films containing the word. Brysbaert and New (2009) argued this is the best value to use when matching words on word frequency.
[b]Similarity was indexed by two values: 1) McRae, et al.'s (2005) semantic feature production norms, in which similarity between two concepts is represented by the cosine, "the dot product between two concept vectors, divided by the product of their lengths" (p. 553). 2) Latent Semantic Analysis norms (LSA, Landauer, et al., 2007), in which similarity is represented by the cosine between two word vectors.
[c]Ortho_N of the target was indexed by Coltheart's N (Coltheart, Davelaar, Jonasson, & Besner, 1977) and refers to the number of orthographic neighbours (word that can be obtained by changing one letter while preserving the identity and positions of the other letters) the target item has. The Ortho_N values were obtained from the English Lexicon Project (ELP) Database (Balota, et al., 2007, available at http://elexicon.wustl.edu/).

Table B2

Overview of the nonword items, matched to the critical word items, and their properties.

Item		Length		Ortho_N[a]	Accuracy[b]	Frequency[c]
Target	Prime	Target	Prime	Target	Target	Prime
GLANSLATOR	jellyfish	10	9	0	0.84	1.61
GLYSCRAPER	sweater	10	7	0	0.97	2.67
DRACKBOARD	picture	10	7	0	0.97	3.50
GLONEWALL	insect	9	6	0	0.94	2.04
SPROOLBOY	magpie	9	6	0	0.91	1.11
STAMEWORK	python	9	6	0	0.91	1.62
CLEATMENT	laptop	9	6	0	0.94	-
OCCENSIVE	garage	9	6	0	0.89	2.91
UBUVERSAL	buckle	9	6	0	1.00	2.33
PROCKINGS	bullet	9	6	0	0.94	3.00
DEVERAGE	hamster	8	7	2	0.80	1.76
ABBUSTOM	echidna	8	7	0	1.00	-
REMETERY	cricket	8	7	1	0.94	1.98
POKTAINS	penguin	8	7	0	0.91	1.79
TOCATION	seagull	8	7	2	0.94	1.54
THOSSARY	balloon	8	7	0	0.94	2.42
GLORPION	phone	8	5	0	0.97	3.65
BAITRESS	tractor	8	7	1	0.88	2.03
TACORONI	razor	8	5	0	1.00	2.40
IFFORTAL	crown	8	5	0	1.00	2.56
SPREDULE	fence	8	5	0	0.97	2.74
CLERAPY	wombat	7	6	0	0.94	0.95
PROCKED	toucan	7	6	3	0.88	0.60
DISTORY	possum	7	6	2	0.88	-
TREMISH	koala	7	5	0	0.84	1.18
PLAMINA	panda	7	5	0	0.81	1.58
TRUCTAR	snail	7	5	0	0.94	1.74
SPISTED	galah	7	5	0	0.94	-
TARSING	bilby	7	5	0	0.94	-
TRIMULI	shark	7	5	0	0.84	2.41
HURRENT	snake	7	5	1	0.91	2.72
BLERVED	cobra	7	5	0	1.00	1.79
PLIMATE	helmet	7	6	2	0.88	2.48
SMOUGHT	mirror	7	6	0	0.88	2.94
ATTIVAL	pearl	7	5	0	0.94	2.48
IPOLATE	brick	7	5	1	0.94	2.41
TISCUIT	chain	7	5	1	0.91	2.87
PLISHED	shell	7	5	0	0.97	2.61
BLEWARD	money	7	5	0	0.91	3.75
FARRACK	ring	7	4	1	0.97	3.32
BLIGMA	bunny	6	5	0	0.97	2.53
GLURVY	leech	6	5	0	1.00	1.71
PREAKS	camel	6	5	3	0.82	2.14
ROIFAR	flea	6	4	0	0.94	2.05
CLIVEL	lice	6	4	0	0.97	1.79
TANNOT	orca	6	4	1	0.97	-
DAMERA	plug	6	4	1	0.94	2.60
SNEWED	tape	6	4	2	0.94	3.17
ALLACK	medal	6	5	0	0.80	2.47

Table B2 (*continued*)
Overview of the nonword items, matched to the critical word items, and their properties.

Item		Length				
Target	Prime	Target	Prime	Ortho_N[a] Target	Accuracy[b] Target	Frequency[c] Prime
GRASMS	menu	6	4	0	0.97	2.60
HIMBLE	card	6	4	2	0.91	3.32
PRELLS	tent	6	4	0	0.88	2.65
SNART	boar	5	4	5	0.80	1.79
THATE	bull	5	4	0	0.88	2.82
NIRED	fawn	5	4	6	1.00	1.30
ABRON	goat	5	4	3	0.91	2.53
PLASK	joey	5	4	3	0.85	2.69
HOINS	slug	5	4	4	0.94	2.28
DROES	ibis	5	4	2	0.97	0.70
FOWER	bear	5	4	10	0.91	3.18
FUMPS	cat	5	3	7	0.94	3.14
BLETS	cod	5	3	3	0.94	1.85
RAIRS	puppy	5	5	7	0.88	2.58
GELON	coin	5	4	2	0.97	2.46
SPLUM	cork	5	4	0	0.90	2.07
FEACH	harp	5	4	6	0.97	1.91
HIXES	wall	5	4	4	0.97	3.32
LIETS	ball	5	4	4	0.97	3.32
LOURS	doll	5	4	7	0.85	2.81
FLERM	cage	5	4	0	0.94	2.75
EPTOL	bank	5	4	1	0.88	3.20
BRIKE	stool	5	5	6	0.85	2.20
CUNKS	table	5	5	3	1.00	3.46
DRALP	frame	5	5	0	0.97	2.74
LANS	eel	4	3	16	0.91	1.72
GRAT	ram	4	3	9	0.85	2.30
CROM	bed	4	3	5	0.94	3.61
VUNS	toy	4	3	5	1.00	2.75
LIR	bug	3	3	8	1.00	2.77
PAB	key	3	3	18	0.94	3.34

[a] Ortho_N of the target was indexed by Coltheart's N (Coltheart, et al., 1977) and was obtained from the ELP Database (Balota, et al., 2007).
[b]Accuracy of the nonword target refers to the proportion of accurate responses for a particular nonword in lexical decision, excluding errors and outliers, as indexed by the NWI_Mean_Accuracy attribute in the ELP Database (Balota, et al., 2007).
[c] Frequency was indexed by lgSUBTLCD (Brysbaert & New, 2009).

Table B3

Overview of the filler word items and their properties.

	Item			Length				Frequency[a]				Similarity[b]			
	Prime in RP				Prime in RP				Prime in RP			LSA in RP			Ortho_N[c]
Target	0.25	0.50	0.75	Target	0.25	0.50	0.75	Target	0.25	0.50	0.75	0.25	0.50	0.75	Target
CATERPILLAR	diploma	bridge	worm	11	7	6	4	1.54	2.02	3.02	2.43	-0.01	-0.04	0.24	0
CERTIFICATE	buzzard	diploma	diploma	11	7	7	7	2.47	1.90	2.02	2.02	-0.05	0.36	0.36	0
TYPEWRITER	squirrel	computer	computer	10	8	8	8	1.97	2.22	3.09	3.09	0.00	0.36	0.36	0
TARANTULA	catapult	spider	spider	9	8	6	6	1.45	1.36	2.37	2.37	-0.02	0.40	0.40	0
CIGARETTE	gazelle	buzzard	cigar	9	7	7	6	2.94	1.54	1.90	2.59	-0.02	0.05	0.26	0
SLINGSHOT	trolley	cigar	catapult	9	7	6	8	1.66	1.68	2.59	1.36	0.11	-0.04	0.02	0
PARAKEET	closet	watch	budgie	8	6	5	6	1.60	2.95	3.77	0.48	0.10	0.10	0.11	0
ANTELOPE	docket	docket	gazelle	8	6	6	7	1.53	1.53	1.71	1.54	-0.02	-0.02	0.18	0
CHIPMUNK	shower	squirrel	squirrel	8	6	8	8	1.48	3.11	2.22	2.22	0.03	0.47	0.47	0
LORIKEET	shield	catapult	parrot	8	6	8	6	-	2.41	1.36	1.98	-	-	-	-
REVOLVER	coupon	gun	gun	8	6	3	3	2.01	1.84	3.47	3.47	0.03	0.42	0.42	2
BUILDING	weasel	frock	house	8	6	5	5	3.38	2.27	1.57	3.78	0.05	0.01	0.20	0
SUITCASE	parrot	trolley	trolley	8	6	7	7	2.57	1.98	1.68	1.68	0.22	0.21	0.21	0
MAGAZINE	spider	parrot	book	8	6	6	4	2.93	2.37	1.98	3.51	0.03	0.08	0.29	0
STRAINER	budgie	gazelle	pan	8	6	7	3	1.08	-	1.54	2.56	-0.03	-0.05	0.20	1
UMBRELLA	computer	budgie	shield	8	8	6	6	2.32	3.09	-	2.41	0.02	0.21	0.14	0
VULTURE	mallet	house	buzzard	7	6	5	7	1.81	1.53	3.78	1.90	-0.01	0.01	0.02	1
TERMITE	radio	ant	ant	7	5	3	3	1.40	3.21	2.05	2.05	0.04	0.40	0.40	0
GIRAFFE	palace	zebra	zebra	7	6	5	5	1.76	2.64	1.77	1.77	0.04	0.68	0.68	0
BATHTUB	train	shower	shower	7	5	6	6	2.35	3.25	3.11	3.11	0.05	0.35	0.35	0
SPATULA	gecko	prawn	ladle	7	5	5	5	1.51	1.20	1.18	1.45	-	-	0.11	0
DRESSER	motor	closet	closet	7	5	6	6	2.20	2.67	2.95	2.95	0.17	0.48	0.48	3
HATCHET	crayon	axe	axe	7	6	3	3	1.86	1.32	2.18	2.18	0.00	0.34	0.34	2

Table B3 (*continued*)
Overview of the filler word items and their properties.

	Item			Length				Frequency[a]				Similarity[b]			
	Prime in RP				Prime in RP				Prime in RP			LSA in RP			
Target	0.25	0.50	0.75	Target	0.25	0.50	0.75	Target	0.25	0.50	0.75	0.25	0.50	0.75	Ortho_N[c] Target
GRENADE	ladle	towel	bomb	7	5	5	4	2.19	1.45	2.72	2.97	0.06	0.01	0.09	1
VOUCHER	bridge	coupon	coupon	7	6	6	6	1.45	3.02	1.84	1.84	0.01	0.21	0.21	0
VILLAGE	basket	town	town	7	6	4	4	2.89	2.63	3.61	3.61	0.22	0.37	0.37	1
RECEIPT	zebra	gecko	docket	7	5	5	6	2.45	1.77	1.20	1.71	-0.01	-	0.01	0
TURKEY	boat	radio	hen	6	4	5	3	2.76	3.16	3.21	2.03	0.04	0.03	0.09	0
ALPACA	mop	plate	llama	6	3	5	5	0.95	2.18	2.97	1.45	0.04	0.06	0.26	-
SHRIMP	bomb	comb	prawn	6	4	4	5	2.39	2.97	2.35	1.18	0.01	-	-0.00	1
DONKEY	pipe	mule	mule	6	4	4	4	2.21	2.81	2.33	2.33	0.07	0.37	0.37	1
MONKEY	jail	ape	ape	6	4	3	3	2.89	3.23	2.24	2.24	0.08	0.39	0.39	1
JAGUAR	sand	basket	lynx	6	4	6	4	1.81	2.79	0.30	0.30	0.06	-0.01	0.14	0
FERRET	book	weasel	weasel	6	4	6	6	1.68	3.51	2.27	2.27	0.01	0.34	0.34	0
LIZARD	shop	bomb	gecko	6	4	4	5	2.06	3.21	2.97	1.20	-0.02	0.02	-	1
OYSTER	shed	clam	clam	6	4	4	4	2.02	2.62	2.20	2.20	0.20	0.37	0.37	1
CANARY	lamp	rock	finch	6	4	4	5	1.99	2.59	3.28	1.81	0.09	0.01	0.16	0
NAPKIN	whip	whip	towel	6	4	4	5	2.14	2.14	2.68	2.72	0.00	0.00	0.25	0
PRISON	worm	jail	jail	6	4	4	4	3.18	2.44	3.23	3.23	0.02	0.71	0.71	1
HAMMER	robe	mallet	mallet	6	4	6	6	2.60	2.45	1.53	1.53	0.06	0.51	0.51	2
ANCHOR	town	finch	hook	6	4	5	4	2.28	3.62	1.81	3.11	0.08	-0.01	0.24	0
SAUCER	coat	lynx	plate	6	4	4	5	1.86	3.11	0.30	2.97	0.09	0.17	0.09	2
TUNNEL	shirt	shield	bridge	6	5	6	6	2.65	3.15	2.41	3.02	0.14	0.22	0.27	1
ENGINE	comb	motor	motor	6	4	5	5	2.91	2.35	2.67	2.67	0.00	0.42	0.42	0
BUCKET	watch	ladle	basket	6	5	5	6	2.59	3.77	1.45	2.63	0.36	0.16	0.30	2
CASTLE	prawn	palace	palace	6	5	6	6	2.58	1.18	2.64	2.64	-	0.54	0.54	1

Table B3 (*continued*)
Overview of the filler word items and their properties.

Item				Length				Frequency[a]				Similarity[b]			
	Prime in RP				Prime in RP				Prime in RP			LSA in RP			
Target	0.25	0.50	0.75	Target	0.25	0.50	0.75	Target	0.25	0.50	0.75	0.25	0.50	0.75	Ortho_N[c] Target
WALLET	finch	purse	purse	6	5	5	5	2.84	1.81	2.83	2.83	0.09	0.40	0.40	4
CANDLE	hook	lamp	lamp	6	4	4	4	2.47	3.11	2.59	2.59	0.06	0.51	0.51	1
VESSEL	frock	boat	boat	6	5	4	4	2.40	1.57	3.16	3.16	0.08	0.45	0.45	0
BLOUSE	llama	shirt	shirt	6	5	5	5	2.27	1.45	3.15	3.15	0.13	0.64	0.64	0
STEREO	cigar	llama	radio	6	6	5	5	2.34	2.59	1.45	3.21	0.06	-0.01	0.17	0
JACKET	canoe	coat	coat	6	5	4	4	2.99	1.89	3.10	3.10	0.22	0.60	0.60	2
SUBWAY	plate	train	train	6	5	5	5	2.53	2.97	3.25	3.25	0.02	0.48	0.48	0
SADDLE	house	worm	seat	6	5	4	4	2.43	3.78	2.44	3.88	0.07	0.04	0.16	2
CARPET	violin	rug	rug	6	6	3	3	2.59	2.09	2.55	2.55	0.03	0.56	0.56	0
PENCIL	towel	crayon	crayon	6	5	6	6	2.59	2.72	1.32	1.32	0.31	0.60	0.60	0
RIBBON	purse	hook	bow	6	5	4	3	2.20	2.83	3.11	2.79	0.25	0.14	0.23	1
CELLO	pan	violin	violin	5	3	6	6	1.61	2.57	2.09	2.09	0.10	0.39	0.39	3
BROOM	rock	pan	mop	5	4	3	3	2.26	3.28	2.57	2.18	0.11	0.18	0.21	4
KAYAK	ant	canoe	canoe	5	3	5	5	1.08	2.05	1.89	1.89	0.05	0.47	0.47	0
CLOCK	bag	fox	watch	5	3	3	5	3.21	3.40	2.61	3.77	0.27	0.10	0.26	8
CLOAK	tap	robe	robe	5	3	4	4	1.97	2.68	2.45	2.45	0.04	0.54	0.54	2
STORE	colt	shop	shop	5	4	4	4	3.33	1.92	3.21	3.21	0.07	0.52	0.52	13
BEACH	hen	sand	sand	5	3	4	4	3.11	2.03	2.79	2.79	0.05	0.73	0.73	7
PASTE	lynx	bow	gel	5	4	3	3	1.86	0.30	2.79	1.83	0.04	0.03	0.28	8
STONE	bow	pin	rock	5	3	3	4	2.97	2.79	2.74	3.28	0.22	0.03	0.15	8
DRAIN	mule	pipe	pipe	5	4	4	4	2.53	2.33	2.81	2.81	-0.02	0.43	0.43	4
STICK	clam	cup	whip	5	4	3	4	3.48	2.20	3.20	2.68	0.11	0.32	0.25	6
BRUSH	seat	seat	comb	5	4	4	4	2.77	3.39	3.39	2.35	0.14	0.14	0.29	3

Table B3 (*continued*)

Overview of the filler word items and their properties.

Item				Length				Frequency[a]				Similarity[b]			
	Prime in RP				Prime in RP				Prime in RP			LSA in RP			Ortho_N[c]
Target	0.25	0.50	0.75	Target	0.25	0.50	0.75	Target	0.25	0.50	0.75	0.25	0.50	0.75	Target
WOLF	pin	tap	fox	4	3	3	3	2.58	2.74	2.68	2.61	0.04	0.03	0.59	2
FOAL	cup	colt	colt	4	3	4	4	1.11	3.20	1.92	1.92	0.01	0.58	0.58	7
TACK	hog	mop	pin	4	3	3	3	1.87	2.29	2.18	2.74	0.19	0.12	0.19	15
BARN	gel	shed	shed	4	3	4	4	2.60	1.83	2.62	2.62	-0.03	0.63	0.63	12
SINK	rug	hog	tap	4	3	3	3	2.81	2.55	2.29	2.68	0.23	0.13	0.24	15
GOWN	axe	book	frock	4	3	4	5	2.42	2.19	3.51	1.57	0.19	0.03	0.65	4
SACK	pie	bag	bag	4	3	3	3	2.70	2.90	3.40	3.40	0.29	0.56	0.56	13
CAKE	gun	pie	pie	4	3	3	3	3.08	3.47	2.90	2.90	0.11	0.62	0.62	18
PIG	hat	gel	hog	3	3	3	3	3.02	3.24	1.83	2.29	0.16	0.04	0.45	12
CAP	fox	hat	hat	3	3	3	3	2.79	2.61	3.24	3.24	0.09	0.52	0.52	18
MUG	ape	hen	cup	3	3	3	3	2.42	2.24	2.03	3.20	0.03	0.02	0.48	11

[a]Frequency was indexed by lgSUBTLCD (Brysbaert & New, 2009).

[b]Similarity was indexed by 1) McRae, et al.'s (2005) semantic feature production norms, and 2) LSA (Landauer, et al., 2007).

[c]Ortho_N of the target was indexed by Coltheart's N (Coltheart, et al., 1977) and was obtained from the ELP Database (Balota, et al., 2007).

Table B4
Overview of the nonword items, matched to the filler word items, and their properties.

Items		Length		Ortho_N[a]	Accuracy[b]	Frequency[c]
Target	Prime	Target	Prime	Target	Target	Prime
ABBOINTMENT	flamingo	11	8	0	0.91	1.60
KITCHANUTTE	jeans	11	5	0	1.00	2.39
ANNOMPLICE	elephant	10	8	0	0.97	2.50
THACESHIP	mosquito	9	8	0	0.97	1.88
PRACTOCAD	trailer	9	7	0	0.97	2.47
FLECTATOR	tissue	9	6	0	0.82	2.59
BUNCTURE	scorpion	8	8	2	1.00	1.75
DRUDENTS	goldfish	8	8	0	0.82	2.00
ILPOSTER	mackerel	8	8	0	0.97	1.95
GRECTRAL	screen	8	6	0	0.97	2.89
SPADIENT	board	8	5	0	0.84	3.23
PROULDER	remote	8	6	0	0.85	2.70
TROSSBOW	folder	8	6	1	0.91	1.79
CHEROIDS	toaster	8	7	0	0.90	2.08
PUDDLONG	cannon	8	6	0	0.94	2.41
VOLLARS	collie	7	6	2	1.00	1.40
DAILBOX	jackal	7	6	1	0.94	1.59
ATTAREL	reindeer	7	8	0	0.91	1.94
HILBAGE	duckling	7	8	0	1.00	1.38
CHESUME	platypus	7	8	0	0.94	0.60
OFFOMAN	baboon	7	6	0	0.97	1.89
SURLING	level	7	5	3	0.61	3.20
BLUWERS	toilet	7	6	1	0.97	2.98
DOARDER	camera	7	6	1	1.00	3.14
SLANDMA	paper	7	5	0	1.00	3.42
HOLLEGE	street	7	6	1	0.97	3.53
TIQUOR	mole	6	4	1	0.97	2.21
NEALTH	finch	6	5	2	0.88	1.81
STORST	husky	6	5	0	0.94	1.56
BLATUE	catfish	6	7	0	0.97	1.72
PINTRY	guppy	6	5	2	0.91	1.18
VALLOP	drum	6	4	2	0.97	2.43
RAMMAL	sheet	6	5	1	0.97	2.67
SPRART	road	6	4	0	0.91	3.44
CLANCE	socks	6	5	2	0.88	2.74
ASBINO	level	6	5	1	1.00	3.20
PARUNG	rope	6	4	0	0.94	2.82
CHRIKE	tray	6	4	0	0.97	2.45
TUNIOR	veil	6	4	1	0.94	2.04
CLOMAX	vest	6	4	1	1.00	2.31
TAGOON	wand	6	4	1	0.91	1.88
PEGEND	apron	6	5	1	0.97	2.03
SMEASY	cape	6	4	0	0.88	2.35
PEFLIN	hose	6	4	0	0.97	2.47
DRATER	wheel	6	5	4	0.94	2.93
TOAFER	hotel	6	5	1	1.00	3.31
BLUPID	ruler	6	5	0	0.97	2.14
GLOSET	letter	6	6	1	0.97	3.25

Table B4 (*continued*)
Overview of the nonword items, matched to the filler word items, and their properties.

Items		Length		Ortho_N[a]	Accuracy[b]	Frequency[c]
Target	Prime	Target	Prime	Target	Target	Prime
NIMONO	pearl	6	5	1	0.97	2.48
CRULLS	prize	6	5	0	0.88	2.87
GLEADY	pass	6	4	0	1.00	3.50
THOOCH	weapon	6	6	0	0.97	3.09
PAITER	hedge	6	5	2	0.85	1.77
SNORLS	tank	6	4	0	0.82	2.83
THIDER	grill	6	5	0	1.00	2.26
ZILLS	taxi	5	4	7	0.97	2.82
TRIME	kitten	5	6	8	0.94	2.20
DOSKS	calf	5	4	4	0.94	2.04
WIGHT	meal	5	4	8	0.88	3.02
DRARP	chick	5	5	0	1.00	2.87
CORLD	rake	5	4	2	0.91	1.95
SLARE	party	5	5	12	0.86	3.57
DOUND	tin	5	3	8	0.94	2.43
NUNKS	peg	5	3	3	0.97	2.91
TROOL	screws	5	6	3	0.91	2.18
GONAR	box	5	3	3	0.97	3.37
PLAME	bat	5	3	6	0.91	2.75
POXER	city	5	4	4	0.88	3.52
DITE	can	4	3	13	0.94	3.92
FUST	tyre	4	4	12	0.91	-
MEEF	kite	4	4	4	0.88	1.89
HOAL	mat	4	3	7	0.88	2.15
NETA	bin	4	3	2	0.94	2.23
WONE	pen	4	3	15	0.97	2.91
HAME	bra	4	3	15	0.90	2.51
BONT	fan	4	3	12	0.94	3.04
COSE	drill	4	5	18	0.86	2.67
ZAD	inn	3	3	11	0.91	2.25
GAM	fly	3	3	18	0.86	3.33
FIM	owl	3	3	12	0.94	2.14

[a] Ortho_N of the target was indexed by Coltheart's N (Coltheart, et al., 1977) and was obtained from the ELP Database (Balota, et al., 2007).
[b]Accuracy of the nonword target refers to the proportion of accurate responses for a particular nonword, excluding errors and outliers, as indexed by the NWI_Mean_Accuracy attribute in the ELP Database (Balota, et al., 2007).
[c] Frequency was indexed by lgSUBTLCD (Brysbaert & New, 2009).

Appendix C

Ethics Approval

Appendix C (pages 202-206) of this thesis has been removed as it may contain sensitive/confidential content

Appendix D

Chapter 2: Published Manuscript

Pages 208-220 of this thesis have been removed as they contain published material. Please refer to the following citation for details of the article contained in these pages:

de Wit, B., & Kinoshita, S. (2014). Relatedness proportion effects in semantic categorization: Reconsidering the automatic spreading activation process. Journal of Experimental Psychology: Learning, Memory, and Cognition, 40(6), 1733–1744. https://doi.org/10.1037/xlm0000004

Appendix E

Chapter 3: Published Manuscript

Pages 222-233 of this thesis have been removed as they contain published material. Please refer to the following citation for details of the article contained in these pages:

de Wit, B., Kinoshita, S. An RT distribution analysis of relatedness proportion effects in lexical decision and semantic categorization reveals different mechanisms. Memory and Cognition 43, 99–110 (2015). https://doi.org/10.3758/s13421-014-0446-6

References

Balota, D. A., Yap, M. J., Cortese, M. J., Hutchison, K. A., Kessler, B., Loftis, B., Neely, J. H., Nelson, D. L., Simpson, G. B., & Treiman, R. (2007). The English Lexicon Project. *Behavior Research Methods, 39*, 445-459.

Brysbaert, M., & New, B. (2009). Moving beyond Kučera and Francis: A critical evaluation of current word frequency norms and the introduction of a new and improved word frequency measure for American English. *Behavior Research Methods, 41*, 977-990.

Coltheart, M., Davelaar, E., Jonasson, J., & Besner, D. (1977). Access to the internal lexicon. In S. Dornic (Ed.), *Attention and performance VI* (pp.535-555). Hillsdale, NJ: Erlbaum.

Landauer, T. K., McNamara, D. S., Dennis, S., & Kintsch, W. (2007). *Handbook of Latent Semantic Analysis.* Mahwah, NJ: Lawrence Erlbaum Associates, Publishers.

McRae, K., Cree, G., Seidenberg, M., & McNorgan, C. (2005). Semantic feature production norms for a large set of living and nonliving things. *Behavior Research Methods, 37*, 547-559.