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Exploring the relationship between spatial and semantic attention: Two limited capacity systems or one?

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ABSTRACT

Attention is associated with benefit and cost due to competition for limited capacity resources involved in access for awareness. Spatial cues guide spatial attention producing benefit for attended stimuli and cost for unattended stimuli. Semantic relatedness shows a similar pattern: primes produce benefit for related and cost for unrelated stimuli, suggesting they work through semantic attention. An unanswered question is how semantic and spatial attention interact: Does the benefit and cost for related stimuli occur because they attract spatial attention? Three accounts of the relationship between semantic and spatial attention were examined: Semantic attention a) works through spatial attention, b) delays disengagement of spatial attention, and c) is independent of spatial attention. In Experiments 1 to 3, participants performed a visual search task for a prime target in a word display and/or a probe discrimination task on a probe target. Experiments 1a and 1b showed that the word and probe tasks were suitable for examining semantic and spatial attention, respectively. Experiments 2a and 2b showed that in the absence of explicit influences on spatial attention, related distractors led to higher word search task accuracy on target present and lower accuracy on target absent trials. Importantly, related distractors did not attract spatial attention as measured by probe task performance, although they did slow responses on target absent trials. Experiment 3 showed that related distractors also do not attract spatial attention when an abrupt onset spatial cue is presented. Instead, spatial attention was slower to disengage from related versus unrelated distractors on target absent trials. Experiments 4 and 5 examined spatial and semantic attention using the temporal order judgment paradigm in which participants judged which of two stimuli occurred first (or second). Related words and abrupt onset spatial cues had different effects on performance: Relatedness did not influence

judgments, but cued words were judged as occurring first more often than uncued words. Taken together, these results suggest that semantic and spatial attention reflect different processes that affect access to awareness. Semantic relatedness does not attract spatial attention, but there is a delay in disengaging spatial attention from related stimuli.

CHAPTER 1. INTRODUCTION AND LITERATURE REVIEW

General Introduction

Ever since Meyer and Schvaneveldt's (1971) seminal work on semantic priming, it has been known that semantically related[1] stimuli are generally processed faster or more accurately than unrelated stimuli. Numerous studies since then have found a benefit on lexical decision and naming tasks for stimuli that are semantically related to a prime (see Neely, 1991, for a review), suggesting that related stimuli are processed more efficiently. What is the implication, though, of more efficient stimulus processing? Is it that these stimuli enter awareness more readily (James, 1890/1950), are actively selected by a mechanism (Posner & Snyder, 1975), or receive more resources than stimuli that do not "fit" the current context (Neisser, 1976)? A more general form of this question might be: Do semantically related stimuli receive more attention than unrelated stimuli?

Consider for a moment what is typically meant by attention. In a hypothetical experiment designed to measure the effects of spatial attention, more information is presented to a subject in a visual search display than what he or she can process simultaneously. Fortunately, a small, dark circle appears immediately before the onset of the search display near the location of one of the to-be-presented stimuli. The results will likely show that targets appearing near this location are responded to faster or more accurately compared to distant targets. In other words, those stimuli appearing near the circle are selectively processed, and researchers have argued that this pattern is the result of limited capacity spatial attention. The limited capacity nature of spatial attention implies that benefit for some stimuli will also produce cost for other stimuli. As I will show later similar findings have been found with stimuli that are related to a prime: benefit for related stimuli and cost for concurrently presented unrelated stimuli. Thus, based on the framework that attention involves selection and is limited in capacity, I would argue that the processing advantage for semantically related stimuli is due to attention.

The question becomes, then, what is the *nature* of this advantage for semantically related stimuli? According to certain theories of attention (e.g., Wolfe's, 1994, guided search model), stimuli with salient visual features and those that share target defining properties rapidly guide spatial attention to their locations, which aids in identification of those stimuli. As described later, stimuli that are semantically related to a prime also show a processing advantage, namely that they appear to be identified more accurately than unrelated stimuli when they are presented in the same display. Accordingly, the question I seek to answer in this dissertation is whether the resources involved in directing attention to locations in space are intertwined with those involved in *semantic attention*. I am interested in whether spatial and semantic attention involve a common or separate pool of limited capacity resources; that is, I am interested in whether the benefits found for processing semantically related stimuli, under conditions of competition for awareness, reflect the use of spatial attention resources, or whether there is a separate set of resources that can be devoted to selecting related stimuli following semantic processing of those stimuli. The clearest evidence for a dependent relationship between semantic and spatial attention would be if task-irrelevant related distractors can be shown to draw spatial attention to their location. Another possibility is that related stimuli do not capture spatial attention, but rather interfere with the disengagement of spatial attention once it is allocated to a related stimulus. I begin by discussing the relevant literature on spatial and semantic attention and describe the patterns of data that would differentiate among three accounts concerning the relationship between spatial and semantic attention. Finally, five experiments are described that address this question and resolve some apparent discrepancies in the literature.

What Is Meant by Selective Attention?

In many situations, humans are faced with the predicament that more visual information is available than can be fully processed at any given time, i.e., processing is limited in capacity. Visual selective attention refers to the phenomenon that during these situations some stimuli receive more processing than others; in other words some stimuli are selected. The mechanism by which attention operates differs according to various theories or frameworks of attention (see Fernandez-Duque & Johnson, 2002; Johnston & Dark, 1986, for reviews), however a common aspect of most theories of selective attention is that attentional resources are limited, and thus only a small number of stimuli or locations can be selected at once (but see Neisser, 1976, for a competing viewpoint). Thus, selective attention is presumed to be operating whenever the preferential processing, or selection, of some stimuli entails a cost for other stimuli occurring in close temporal or spatial proximity as a result of competition between stimuli (Desimone & Duncan, 1995).

Spatial Attention

Much of the research on visual selective attention has examined spatial attention, or how attention is allocated to locations in visual displays. The results of many studies suggest that spatial attention acts like a 'spotlight' (e.g., Posner, Snyder, & Davidson, 1980) in that it selects or illuminates a single region of the visual scene (see Cave & Bichot, 1999, for a review). Stimuli appearing within that area are attended, while the processing of stimuli outside the spotlight is attenuated. For example, Posner (1980) found that subjects were faster to respond to targets presented at locations pre-indicated by a valid spatial cue compared to a cue absent condition, while responses were slowed when the target appeared at a non-cued location (i.e., following an invalid cue). The spatial cue ostensibly served to direct the spotlight of attention to the cued location, which facilitated performance when the target appeared at that location and impeded performance when the target occurred at a different location due to the spotlight not being there, or the delay associated with shifting the spotlight to the target's location.

Other studies provide converging evidence that the relationship between the allocation of attention in space and the location of targets is an important factor for target identification. For example, Hoffman and Nelson (1981) showed that detection of a target was facilitated when it appeared spatially adjacent to a different, preceding target. Similarly, detection of targets in rapidly presented multi-element displays is facilitated when those targets appear at the same rather than a different location (Cave & Pashler, 1995). Finally, other studies show that response incompatible distractors decrease accuracy when they are presented spatially close (approximately 1^0 visual angle) to the target versus when they are further away (Eriksen & Hoffman, 1972). Thus, targets appearing near a currently attended location are responded to faster or more accurately or both compared to more distant ones, and close distractors produce more interference than distance ones.

Two types of signals have been used for directing visual spatial attention: exogenous cues and endogenous cues. Exogenous cues often are abrupt visual onsets that typically appear in the periphery of a display and produce reflexive shifts in spatial attention to their location (Jonides, 1981; Yantis & Jonides, 1984). Conversely, endogenous cues are symbolic cues, such as an arrow presented in the center of a display pointing towards a target's probable location, that influence spatial attention through a goal-directed process (Posner, 1980; Posner et al. 1980). There are several differences in the manner by which these cues influence spatial attention. First, exogenous cues produce more rapid shifts in spatial attention than endogenous cues (Müeller & Rabbitt, 1989). Additionally, the spatial shifts of spatial attention caused by exogenous cues are more automatic or involuntary than those caused by endogenous cues, particularly when the location of the target is uncertain (Müeller & Rabbitt; Yantis & Jonides, 1990). Finally, there is some evidence to suggest that endogenous cues do not always enhance processing of all stimuli occurring at indicated locations, particularly when the stimuli are unexpected (Klein & Hansen, 1987) or when the cue's validity, the likelihood that the target will occur at its location, is low.

In addition to allocation based on cues, spatial attention can also be allocated based on a stimulus' visual properties. For example, in the visual search paradigm subjects typically make a binary response to a target presented amongst distractors. Target responses can be slowed, however, by the presence of a distractor with a unique color (Theeuwes, 1992) or one that appears abruptly (Yantis & Jonides, 1984), which some have argued (e.g., Theeuwes) implies that these types of stimuli capture spatial attention to their location. Thus, attention can be allocated in a bottom-up method where spatial attention is drawn to the most unique or salient stimulus in the display. However, in some cases response times (RTs) to targets are not influenced by the appearance of unique distractors, for instance when the target and unique distractor are defined by different properties (Folk, Remington, & Johnston, 1992) or when the properties of the target and distractors are known ahead of time (Bacon & Egeth, 1994). These results show that attention can also be allocated in a top-down, or goal-directed manner, which is a method of selection that operates based on observers' expectations. Thus, spatial attention can be allocated based either on a stimulus' visual salience or its relevance for making a target response. This conceptualization of spatial attention is consistent with Wolfe's (1994) guided search model, in which the deployment of spatial attention in a visual search task is influenced by the visual salience of stimuli in the display (bottom-up information) as well as the qualities that best distinguish the target from distractors (top-down information).

While visual search tasks do offer some insight into spatial attention, they do not typically provide a precise measure of where spatial attention is being directed within a display at any given time. For example, consider an experiment by Theeuwes (1992) in which subjects responded to the orientation of a line embedded inside a target circle presented amongst diamonds that also had lines inside them. On some trials one of the diamonds was presented in a unique color, and RT to the target was slowed compared to when all stimuli were the same color. From these results one might conclude that the uniquely colored distractor attracted spatial attention, even though color was irrelevant for detecting the target. However, an alternative explanation is that the distractor delayed the response to the target by influencing a decision stage of processing rather than by directly capturing spatial attention. Accordingly, Remington, Folk and McLean (2001) showed that when a response-incompatible distractor appeared at a location cued by a stimulus that did not share the target's defining property (e.g., the cue was a motion singleton and the target was a color singleton), there was no evidence that spatial attention was drawn to the distractor location. Specifically, responses were not slowed when a response-incompatible distractor versus a neutral distractor appeared at the cued location, which would have been expected if the cue did attract spatial attention. Thus, slower RTs on visual search tasks, for instance when a salient distractor is added, do not necessarily imply that the distractor captured spatial attention.

Fortunately, there are several effective techniques for measuring the deployment of spatial attention in displays. One technique is through monitoring eye movements. Research has shown that there is a strong relationship between fixated and attended locations. For example, Hoffman and Subramaniam (1995) found that subjects were faster to respond to a target appearing at the location to which they were instructed to make an eye movement even when they knew that the target was more likely to appear at a different location. Deubel and Schneider (1996) extended this finding by showing an advantage for detection of targets occurring at the location of saccades even when the target's location was known ahead of time with complete certainty. In fact, performance was near chance when the target occurred at a location other than the programmed saccade's location. However, others have shown that spatial attention can also be directed covertly, a shift of attention without moving the eyes, to non-fixated locations (e.g., Posner, 1980). Overall, these findings suggest that spatial attention cannot be easily separated from fixated locations, at least when a saccade is required (i.e., it might be easier to separate spatial attention from eye movements while maintaining fixation), and that the movement of spatial attention and programming of saccades may involve similar mechanisms (Rizzolatti, Riggio, Dascola, & Umiltà, 1987). Thus, eye fixations can provide a useful index of where spatial attention is being allocated in a display (see also McPeek, Maljkovic, & Nakayama, 1999), but the precise location of spatial attention cannot be determine with complete certainty because spatial attention can be shifted covertly.

A second technique for measuring the deployment of spatial attention is the probe detection task. In this paradigm a probe target, usually a small dot or letter, is presented following a display, typically at a location previously occupied by a stimulus (e.g., Kim & Cave, 1995; LaBerge, 1983). Accuracy or RT to respond to the probe is used as an indicator of where spatial attention was allocated in the previous display, with faster or more accurate responses indicating that spatial attention was directed to a stimulus in the preceding display that appeared at or near the probe's location. For example, LaBerge had subjects either identify the central letter of a word or decide whether the word was a proper noun. A probe sometimes appeared immediately after the offset of the word at the location of any of the letters in the word. Following the letter identification task, subjects were faster on the probe task when the probe appeared at the central letter's location and were slower when it appeared at a letter towards the ends of the word. Following the word discrimination task, however, there was no effect of letter position on probe RT. These results suggest that in the letter identification task, spatial attention was directed to the central letter of the word and shifts of attention, which took time, were required to respond to probes that appeared at other locations. Conversely, in the word identification task, spatial attention was distributed over the entire word and thus no effect of probe position was found. This result is conceptually similar to those described earlier that showed superior detection of stimuli occurring spatially close to an attended stimulus' location. Thus, the probe detection task can also be a useful method for determining where spatial attention is being deployed in a display.

Semantic Selective Attention

The previous section addressed how stimuli can be selected on the basis of their spatial location. Another factor that appears to influence selection of stimuli into awareness is semantic attention, or a stimulus' semantic relationship to a prime or context. For example, Dark, Vochatzer, and VanVoorhis (1996) presented subjects with backwards masked word pairs following a prime word. In Experiment 1, the prime was sometimes semantically related to one of the words in the word pair, and subjects were instructed to report both words. Dark et al. found that more related than unrelated words were reported and that there was a cost for the report of unrelated words in the same display as a related word compared to a neutral prime condition. Based on the theoretical notion that attention is associated with benefit to attended and cost to unattended stimuli, they concluded that semantically related words were selectively attended over unrelated words. Consequently, these words were assumed to be more likely to enter awareness, and be reported, compared to unrelated stimuli.

Other studies using a range of different methodologies have reported conceptually similar results. All are consistent with the general framework that prime related stimuli are processed more efficiently than unrelated stimuli through a mechanism such as spreading activation (Collins & Loftus, 1975), expectancy (Becker, 1976; Becker & Killion, 1977) and/or strong connections formed between a pair of commonly associated stimuli (Ratcliff & McKoon, 1988). These studies can be grouped into three separate lines of research: attention to objects in natural scenes, attention to objects in artificial scenes, and word identification in brief displays.

Attention to Semantically Inconsistent Objects in Natural Scenes

Within the scene perception literature, many studies have shown an advantage for the identification of stimuli that are semantically consistent with the context of a scene. A classic study by Palmer (1975) found that subjects were better at recognizing objects that were consistent versus inconsistent with the context of a preceding line drawing (e.g., a loaf of bread versus a mailbox following the presentation of a kitchen scene). Another early study by Biederman, Mezzanotte, and Rabinowitz (1982) also provided evidence that scene consistent objects are better recognized. Subjects were shown a label naming a target object, followed by a scene for 150 ms and a cue indicating a location in that scene. The task was to decide whether the named object appeared at the cued location, and performance was better when the target was semantically consistent with the scene versus when it was inconsistent (but see Hollingworth & Henderson, 1998, for a critique). Finally, recent studies by Davenport (2007; Davenport & Potter, 2004) showed that subjects were better at identifying foreground objects that were presented on a scene consistent background, as well as backgrounds that were presented with scene consistent foreground objects.

While these results are intriguing, they do not reveal whether the benefit for identifying scene consistent stimuli involves limited-capacity attention or other processes involved in object recognition, such as binding shapes into meaningful objects. Other studies, however, have specifically addressed whether semantically informative regions in scenes influence attention. One of the first such studies was conducted by Loftus and Mackworth (1978). They monitored subjects' eye movements as they viewed a series of scenes ostensibly for a memory task. Some scenes contained semantically inconsistent objects (e.g., an octopus in a farm scene). The results showed that subjects spent more time fixating scene inconsistent objects and that these objects were fixated earlier than context consistent objects. Recall from a previous section that fixated locations are used as an indicator of where spatial attention is deployed in a scene. Thus, these results suggest that semantically inconsistent objects attract spatial attention. It should be noted, though, that more recent studies have failed to find that inconsistent objects are fixated sooner than consistent objects, but they did show that inconsistent objects are generally fixated longer than consistent objects (De Graef, Christiaens & d'Ydewalle, 1990; Henderson, Weeks, & Hollingworth, 1999). Therefore, scene inconsistent stimuli do appear to be spatially attended longer than consistent stimuli, but they may not directly capture spatial attention, per se.

Gordon (2006) used a negative priming paradigm to investigate whether scene inconsistent objects attract attention. Negative priming is the finding that RTs to targets are slower when those stimuli recently appeared as distractors (Tipper, 1985). One explanation for negative priming is that representations of distractors can be inhibited to aid in target identification, and the inhibition remains for a short period of time causing slower RTs when that stimulus appears subsequently as a target. In Gordon's study, subjects viewed scenes containing several scene consistent objects and sometimes one inconsistent object, followed by a letter string to which they made a lexical decision. When the letter string was a word, it named an object that was present or absent in the preceding scene and that was consistent or inconsistent with the preceding scene's context. Gordon found that RTs to scene consistent words were slower when the named object appeared with an inconsistent object in the preceding display. This result suggests that the inconsistent object attracted attention, leading to inhibition of other stimuli in the scene (i.e., the consistent ones). Gordon thus concluded that attention can be guided by semantics and that scene inconsistent objects attract attention.

A study by Walter and Dassonville (2005) also demonstrated that semantically related stimuli can capture spatial attention. They used the change blindness paradigm to explore whether attention would be guided to semantically related objects in natural scenes. Change blindness refers to the finding that people are quite poor at detecting changes in displays when the low-level visual discontinuity caused by a changing feature is masked (Rensink, O'Regan, & Clark, 1997; Simons & Levin, 1998). Directing spatial attention to the location of the changing feature, however, has been shown to improve performance (Rensink, 2002; Rensink et al.). Walter and Dassonville presented their subjects with the name of an object followed by a scene. On some trials the named object was the one that changed, while on other trials a different object in the scene changed. Subjects were faster to detect the change when the named object changed, even when the name was degraded to the point that it could not be read aloud. Walter and Dassonville concluded that prime related objects attract spatial attention. Unfortunately, this result is open to several alternative explanations. For instance, subjects may have purposely attended to the named objects first. Thus, this finding could be caused by top-down attentional selection rather than (involuntary) semantic selection. Also, the benefit for the named object may not be due to semantic attention, as subjects could have searched for the named object based on its visual features rather than its meaning. Overall, however, these studies tend to suggest that semantically meaningful objects in natural scenes influence attention.

Attention to Semantically Related Objects in Artificial Scenes

Semantic guidance of attention has also been examined in artificial scenes, for example ones that contain isolated objects without a background. There is some evidence to suggest that object recognition processes operate similarly in these types of displays as they do for natural scenes. Auckland, Cave, and Donnelly (2007), for instance, found that subjects were better at recognizing a centrally presented target object when four objects in the periphery were associated with the target versus when they were not (e.g., recognizing playing cards amongst gaming equipment versus fruits). This finding is similar to the studies discussed earlier that demonstrated an advantage for identifying scene consistent objects (e.g., Palmer, 1975). As before, though, it is unclear whether this benefit is due to processes associated with attention or object identification.

Other studies have investigated whether semantically related or consistent stimuli capture attention in artificial displays. One study that suggests they do was conducted by Moores, Laiti, and Chelazzi (2003). A prime word was presented at the start of each trial and was followed by a four object display. Some displays contained a target, an object depicting the prime word. Some displays also contained a related distractor (e.g., prime = motorbike; related distractor = helmet), while others contained only unrelated distractors. In Experiment 1, subjects first responded to whether the target was present or absent, and then reported as many other stimuli that appeared in the display as possible. Report of related distractors was significantly higher than unrelated ones, which Moores et al. suggested was caused by related distractors attracting attention, or being easier to remember. In Experiment 3, subjects performed the target detection task along with a probe detection task, which involved determining whether a black dot occurred at the left or right side of the display. The purpose of the probe task was to discern whether related objects attract spatial attention. Recall that probes are responded to faster or more accurately when spatial attention is directed near those stimuli. Thus, if related objects attract spatial attention, then probes appearing near a related object should be responded to faster than when the probe appears near an unrelated object. Interestingly, subjects were not faster to detect probes appearing at the location of related versus unrelated distractors. Somewhat surprisingly, subjects were also not faster when the probe appeared at the target's location. Instead, probe detection was slower following displays containing targets or related objects, suggesting that the presence of a target or related object in the object display generally delayed responses to the probe target. However, one potential problem with interpreting these results is that their probe task was a simple detection task, determining whether the dot appeared on the left versus the right side of the display. This task may be performed without the focusing of spatial attention on the probe, and thus performance may not be affected by the location of the target or related word in relation to the probe, explaining the very surprising result that probe responses were not faster or more accurate when the probe occurred at the target's location. Finally, in Experiment 5 subjects' eye movements were monitored while they performed the target detection task. A higher proportion of initial saccades were made towards related versus unrelated distractors, suggesting that related distractors captured spatial attention. Overall, Moores et al. concluded that attention can be allocated based on the semantic characteristics of objects in a scene, although their results were ambiguous as to whether the semantically related stimuli influenced spatial attention or a spatially invariant set of limited capacity resources.

Research by Humphreys and colleagues has extended these findings. Belke, Humphreys, Watson, Meyer, and Telling (2008) showed that increasing perceptual load (number of distractors) and cognitive load (remembering five versus zero digits until the end of the trial) had only a minor influence on the ability of target related stimuli to capture attention. Specifically, RTs to detect the target were slower when semantically related distractors were present, and first fixations were more likely to be made to those distractors than unrelated ones regardless of perceptual or cognitive load. Furthermore, Meyer, Belke, Telling, and Humphreys (2007), in addition to replicating the findings of Belke et al., demonstrated that a similar effect occurs for homophones of the target (e.g., boy - *buoy*), suggesting that a similar impact to that of target related stimuli can be found for stimuli that sound like the target. Overall, the finding of attention capture by related stimuli appears to be relatively robust.

In other studies, instead of being presented with a target to search for, subjects are shown a set of objects and given an auditory instruction about objects in the display, a procedure known as the visual-world paradigm (Cooper, 1974; Tanenhaus, Spivey-Knowlton, Eberhard, & Sedivy, 1995). Eye movements are recorded while subjects hear the sentence, and fixations are used as an indicator of which candidate objects subjects are considering. For example, subjects may hear the sentence "go to the car," and be simultaneously presented with a display of objects consisting of a chair, house, bottle and car. In one such study, Dahan and Tanenhaus (2005) showed subjects displays containing four objects and asked them to indicate a named object using the mouse. Some trials contained a visually similar object (e.g., snake - *rope*). Although the objects were displayed for up to 1,000 ms prior to the presentation of the name, subjects fixated visually similar distractors for a greater proportion of time than visually distinct distractors, suggesting that visually similar objects attracted spatial attention (see also, Huettig & Altmann, 2007; Huettig & Hartsuiker, 2008).

Similar effects have been found for semantically related distractors. For instance, when subjects were asked to name an object in a display based on its visual characteristics (e.g., name the circular object - *plate*), eye fixations were more common to associated distractors (e.g., *stove*) that appeared in the same display than to unrelated ones (Huettig & Hartsuiker, 2008). Note that the opposite is also true: When subjects named objects based on their semantic characteristic (e.g., the musical instrument - *saxophone*), visually similar distractors (e.g., *ladle*) attracted eye fixations. Huettig and Altmann (2005) also found similar results for distractor stimuli from the same semantic category as the target (e.g., piano - *trumpet*), even when these distractors were presented in the same display as the target (see also Yee & Sedivy, 2006). Thus, the results of these studies show that semantically related distractors in artificial scenes attract spatial attention.

Other researchers have developed novel paradigms for investigating the behavioral effects of semantic relatedness. For example, Huang and Pashler (2007) presented subjects with a prime word to be maintained in working memory for an end of trial matching task, followed by three words and then three digit probes, one appearing at the location of each word. The task on each trial was to report any of the three digits. Numerous studies have found that stimuli that share visual features with one held in working memory capture attention (e.g., Soto, Heinke, Humphreys, & Blanco, 2005). While none of the three words matched the prime word visually, one of them was always semantically related to the prime. The results showed that the digit presented at the location of the semantically related word was chosen at a significantly higher rate than the other digits at long (i.e., > 400 ms) stimulus onset asynchronies (SOAs). Thus, these results suggested that the related word attracted attention by biasing subjects to report the digit that subsequently appeared at its location.

Finally, a study by Koivisto and Revonsuo (2007) nicely demonstrates how semantic relatedness can influence attention. Under conditions of inattentional blindness, subjects often fail to notice an above threshold stimulus presented at the center of a display when their attention is engaged by a peripheral task (Mack & Rock, 1998). In their study, the subjects' primary task was to detect animal or furniture stimuli in the periphery. On a critical trial, however, an unexpected animal or furniture stimulus was presented in the center of the display. Koivisto and Revonsuo found that when the unexpected stimulus was from the same semantic category as the target in the primary task (e.g., an unexpected bookshelf was presented while subjects were searching for furniture stimuli), subjects were about twice as likely to notice it. Overall, attention appears to be biased towards semantically related stimuli in artificial as well as natural displays.

Some results of studies from this section seem to contrast with ones from the previous section. Namely, it appears that spatial attention is captured both by scene inconsistent (Loftus & Mackworth, 1978) and by scene consistent (Belke et al., 2008; Meyer et al., 2007; Moores et al., 2003) stimuli. This apparent contradiction may be due to methodological differences. Specifically, Loftus and Mackworth had subjects search natural scenes, while Belke et al., Meyer et al. and Moores et al. presented subjects with a number of individual objects, and on some trials one of those objects was related to a prime. Semantic attention may operate differently under these situations. When all stimuli but one are semantically consistent with each other, the inconsistent stimulus appears to attract semantic attention. When several stimuli are presented and only one of them is consistent with, or related to, a prime, the related stimulus appears to attract semantic attention. In both situations the semantic relationship between a stimulus and its context, produced either by a prime or the other stimuli in a display, influences semantic attention, and the most semantically salient stimulus, the one context inconsistent stimulus or the one prime related stimulus, appears to attract spatial attention.

Studies of Word Identification in Brief Displays

A final set of studies has examined semantic attention using briefly presented word displays. What makes these studies different from traditional semantic priming studies (e.g., those reviewed by Neely, 1991) is that multiple to-be-named words are presented under impoverished conditions, which causes competition between the representations of those words for awareness. The assumption is that words that compete better for limited capacity resources are more likely to enter awareness and be reported. As described previously, Dark et al. (1996) found that subjects were more likely to report words that were semantically related to a previous prime and less likely to report unrelated words compared to neutral prime trials in which neither word in a word pair was related to a prime. A follow-up experiment (Experiment 3) confirmed that this was true even when the subjects' task was to report the word that was exogenously cued by an abrupt onset spatial cue, and hence a word's semantic relationship to the prime was task irrelevant. Schwarting and Johnson (1998) reported similar results. In their study, subjects were presented with a prime word followed by a display in which zero, one or two words in a word pair were semantically related to the prime. Subjects were instructed to report both words. Benefit was found for report of related words, along with cost to report unrelated words in the same display as a related one.

Finally, Davenport and Potter (2005) presented subjects with two streams of character strings above and below one another in a rapid serial visual presentation display. Two target words were presented, one in each stream, one of which was sometimes related to a prime word presented at the beginning of each trial. The results showed that more related than unrelated words were reported whether subjects were instructed to report both word targets (Experiment 1) or just the related word (Experiment 2). Unlike Dark et al. (1996) and Schwarting and Johnston (1998), however, no cost was found for report of simultaneously presented unrelated words. Overall, these studies suggest that semantically related words show a processing advantage compared to unrelated words, and as a result are more likely to be reported. Some studies (e.g., Dark et al.; Masciocchi & Dark, in revision; Schwarting & Johnston) also show cost for concurrently presented unrelated stimuli. Thus, based on the definition presented earlier, these studies suggest that semantically related stimuli receive more attention than unrelated stimuli.

Note that in the studies described in the previous three sections a stimulus' semantic relationship with the prime or scene context is task irrelevant. It would not be too surprising, for instance, if subjects are able to rapidly locate or report related stimuli when instructed to do so. In this circumstance, semantic attention would be confounded with top-down selection. Instead, these studies provide evidence that pre-activation of a stimulus' semantic meaning influences attention even when its meaning is task irrelevant. Also, as mentioned earlier, the purpose of this dissertation is to explore the relationship between spatial and semantic attention. Many of the studies reviewed in the previous three sections provide some insight as to whether semantic attention involves the same resources associated with spatial attention. However, most of these studies do not make an explicit distinction between spatial attention and limited capacity resources associated with access to awareness, and the results of other studies are ambiguous as to whether or not spatial attention resources are involved. Thus, the term attention has been used in its broadest sense, and no inferences should be drawn about the relationship between semantic and spatial attention unless the term spatial attention was explicitly used. Studies that provide insight on the relationship between semantic and spatial attention will be considered more closely in the following sections.

Interaction Between Semantic and Spatial Attention

While the notion of semantic selective attention is still relatively novel, there does appear to be ample empirical evidence that a stimulus' meaning influences its ability to enter awareness. The studies discussed so far demonstrate that there are (at least) two ways in which a stimulus can be selected: spatially, based on its location, or semantically, based on its meaning or relationship to a prime or context. An unresolved question, however, is how these two modes of selective attention relate to each other. For instance, is it the case that humans possess a single, unitary mechanism of attention, and the advantage observed for semantically related stimuli is a result of their attracting spatial attention? Or, are two distinct, independent processes involved in spatial and semantic attention?

It should be noted that many studies have found a reduced or complete lack of semantic processing of stimuli appearing outside the focus of spatial attention (see Lachter, Forster, & Ruthruff, 2004, for a review). If true, these findings strongly suggest that some amount of spatial attention is required for semantic processing, and thus semantic attention cannot be fully dissociated from spatial attention. However, the current question is not whether semantic processing can occur independently from spatial attention, but whether semantically related stimuli attract spatial attention more so than unrelated stimuli.

It is not uncommon in the attention literature for multiple modes of attention to be hypothesized. For instance, one distinction that has received extensive support is that between spatial and object based attention. Object based attention refers to the finding that attention can be selectively directed to the entirety of a single object, and not unavoidably to overlapping objects occurring at the same spatial location (e.g., Duncan, 1984; Rock & Gutman, 1981). Egly, Driver, and Rafal (1994) showed, for example, that RTs to targets appearing at the opposite end of a spatially cued object were faster compared to targets on a different object that were the same spatial distance away. This result suggests that there might be multiple types of attentional resources, which can be recruited separately depending on task requirements. In support of this framework, Fink, Dolan, Halligan, Marshall, and Frith (1997) showed that spatial and object based attention are subserved by distinct brain regions, although many of the same regions were activated by both modes of attention.

Several behavioral and neurological studies will now be described, some of which were described previously, which offer evidence as to whether the benefit for the selection of semantically related stimuli involves the same resources that are associated with spatial attention. Unfortunately, as will be become apparent, no clear pattern of results has emerged.

Evidence for a Single Set of Attentional Resources

Several studies seem to show that semantic and spatial attention influence the same resources. For example, using a similar procedure to Dark et al. (1996), Masciocchi and Dark (in revision) presented subjects with a pair of words. Some groups of subjects saw word pairs in which one word was always related to the prime, and for some groups an abrupt onset spatial cue was presented prior to the word pair display but adjacent to one of the subsequent words' locations. In certain conditions, related words and spatial cues were present in the same display. Across groups, instructions were to report both words, the related word, or the spatially cued word. Regardless of instructions, however, a significant interaction was always found between relatedness status and cue status, such that the spatial cueing effect (the advantage for reporting spatially cued over spatially uncued words) was stronger for words that were semantically related versus unrelated to the prime. Based on additive factors logic (Sternberg, 1969), this pattern suggests that the processes behind semantic and spatial attention share at least one stage in common.

Another piece of evidence that semantic attention involves similar resources as spatial attention comes from the eye tracking studies discussed previously. According to the premotor theory of attention (Rizzolatti et al., 1987), spatial attention precedes eye fixations to new locations. Thus, the findings that show eye fixations are drawn to semantically related stimuli (e.g., Moores et al., 2003) imply that these stimuli also draw spatial attention (although this finding was not replicated by Masciocchi & Dark, in revision), suggesting the benefit for semantically related stimuli may be the result of those stimuli attracting spatial attention.

Neurological studies might be informative for investigating the relationship between spatial and semantic attention. Imaging studies have shown that word processing takes place primarily in the left temporal lobe, specifically in regions of the fusiform gyrus (Nobre, Allison, & McCarthy, 1994), as well as regions of the left prefrontal cortex (Devlin, Matthews, & Rushworth, 2003), among others. Related words following a prime tend to produce less activity in these regions compared to unrelated words, suggesting they are being processed more fluently.

A few imaging studies have specifically investigated whether regions of the brain involved in spatial attention are influenced by the presence of semantically related stimuli. An early PET study by Petersen, Fox, Posner, Mintun, and Raichle (1988) showed that areas involved in spatial attention, such as the anterior cingulate gyrus, are active during semantic processing of words. In a more recent study by Gronau, Neta, and Bar (2008), subjects were presented with target objects (e.g., dresser) that could be semantically consistent (e.g., mirror) or inconsistent (e.g., pot) with another object in the display. The objects could also appear in a spatially consistent (on top of dresser) or inconsistent (below dresser) arrangement. The subjects' task was to decide whether the target was a real object or a nonsense object. Behaviorally, the advantage for detecting real objects was larger for semantically consistent versus inconsistent objects, but only when the objects appeared in a spatially consistent configuration. For the neurological data, the authors focused on regions of activity that exhibited the Semantically consistent x Spatially consistent interaction found in the behavioral data. Several regions believed to be involved in top-down control of attention, such as the prefrontal cortex, showed higher activation for semantically consistent versus inconsistent objects but only in spatially consistent configurations. Thus, processing of objects' representations appears to be influenced by a combination of semantic and spatial contextual factors. Note that earlier it was mentioned that less activation was associated with relatedness. Both interpretations are found in the literature.

Evidence for Two Independent Sets of Attentional Resources

In contrast to the studies described in the previous section, the results from many other studies suggest that spatial and semantic attention may involve different resources. For example, Dark et al. (1996) found no interaction between relatedness status and spatial cue status in multiple experiments, and thus concluded that the two processes are independent. Stolz (1996) concluded that capture of attention by exogenous cues is not influenced by semantic relatedness, but that semantic relatedness might nevertheless influence the shifting of spatial attention. In one experiment subjects responded to the identity of a symbol target, which was preceded by a valid or invalid spatial cue. The cue was a word that was related or unrelated to a prime presented at the start of the trial. Thus, the spatial cue could be valid or invalid, and related or unrelated to the prime. Stolz found an interaction between cue validity and whether the word was related or unrelated. Specifically, RTs to the target on invalid trials were slower when the cue was related to the prime versus when it was unrelated. However, on valid trials there was no benefit for targets at the location of semantically related cues. Overall, Stolz concluded that the capture of attention by abrupt onset spatial cues is best described as an encapsulated process, as RT to the targets following valid cues was unaffected by whether it was related or unrelated. However, attentional disengagement from the cue word was slowed when it was related, suggesting that related words held subjects' spatial attention at the cued location, hindering their ability to disengage from the related word.

In another study, Stolz and Stevanovski (2004) had subjects perform a lexical decision task on a word that could occur at one of two locations and that was sometimes related to a prime. An exogenous spatial cue appeared prior to word onset and was either predictive (80% valid, Experiment 1) or non-predictive (50% valid, Experiment 2) of the word's location. When the cue was predictive, a significant interaction between cue validity and relatedness status was found, with larger cueing effects for unrelated words. However, the interaction disappeared when the cue was non-predictive of the word's location, and the effects of cue validity and relatedness became additive. Stolz and Stevanovski's explanation for this pattern was that spatial cues influence the uptake of visual information, while related primes provide a top-down benefit for related words that can be used to minimize the cost of invalid cues. Thus, Stolz has argued that spatial and semantic influences on attention exist, but that they reflect separate processes.

Stolz's (1996) explanation for the Semantic relatedness x Cue validity interaction, that semantically related stimuli do not influence capture of attention but do delay attentional disengagement, also calls into question the interpretation of some eye movement studies that show prolonged fixations for semantically consistent stimuli in artificial displays. Some have argued that this pattern indicates that semantically related stimuli draw spatial attention to their location. However, it could the case that semantically related stimuli cause fixations to their locations to be prolonged rather than that they attract spatial attention to their location sooner. Consistent with this explanation, for some studies the difference between related and unrelated distractors in proportion of fixation time was not significant until 600 ms after onset of the display (e.g., Yee & Sedivy, 2006). Because initial fixations typically occur approximately 200 ms after display onset, it is impossible to tell from those data alone whether semantically related stimuli captured spatial attention sooner or merely held spatial attention longer. However, it should be noted that other studies have found that first fixations are more likely to be made to related versus neutral distractors (e.g., Belke et al., 2008; Meyer et al., 2007; Moores et al., 2003), which would not be accounted for by Stolz's disengagement explanation.

As discussed previously, researchers have found several areas of the brain that respond differently to the presentation of related and unrelated stimuli. Some have argued that these regions are distinct from the regions involved in spatial attention. The spatial attentional system appears to be subserved by much of the right hemisphere, including areas of the frontal, temporal and parietal lobes (Corbetta & Shulman, 2002). Posner (1992; Posner & Petersen, 1990) has argued that areas of the brain responsible for shifts of spatial attention, what he calls the posterior attention system, are separate from areas of the brain responsible for selecting stimuli based on their meaning, the anterior attention system.

Some direct evidence suggests that the neural substrates of spatial and semantic attention are more independent than what was suggested by Gronau et al. (2008). In an fMRI study, Cristescu, Devlin, and Nobre (2006) presented symbolic cues (+, x, #) that indicated either the probable semantic category (animal or tool) or spatial category (left or right visual field) of a letter string to which subjects made a lexical decision. Because the cue provided either spatial or semantic information, Cristescu et al. were unable to examine any behavioral interaction between spatial and semantic attention. The imaging results did indicate that certain brain regions were activated by semantic cues but not spatial cues, including the left inferior frontal cortex, left parietal regions, and other regions of the left-hemisphere important for semantic analysis of words. This finding suggests that distinct brain regions may be involved in semantic and spatial attention. There were several regions activated by both semantic and spatial cues, though, including the posterior parietal cortex and areas of the frontal lobe including the frontal eye fields.

Using an almost identical task, Cristescu and Nobre (2008) recorded event related potentials to measure the time course of spatial and semantic attention. When the cue indicated the likely spatial position of the target, the P1 component was found to be larger following valid than invalid cues, which suggests the spatial cue influenced spatial attention. The N400, which is often found for language processing tasks, was also larger (i.e., more negative) following valid than invalid spatial cues. When the cue indicated the likely semantic category of the target, there was no difference for the P1 for valid versus invalid cues, but valid cues did weaken the N400 (i.e., cause it to be more positive). Thus, while spatial and semantic cues did influence some of the same components, spatial cues appeared to influence attention much earlier than semantic cues. Furthermore, the fact that the N400 was modulated by both semantic and spatial cues does not necessarily mean that the same brain regions were influenced by both cue types. In support of this possibility, the topographies of the N400 differed significantly for semantic and spatial cues. Overall, these results suggest that semantic and spatial attention may involve largely independent resources and brain regions.

Overview of Present Research

The relationship between the resources involved in spatial attention and semantic attention is unclear. There is some evidence that semantically related stimuli draw spatial attention to their location. However there is also evidence that semantic and spatial attention involve separate resources. In other words, the extent to which the advantage for processing semantically related stimuli involves directing spatial attention to a related stimulus' location is ambiguous.

Contrasting three possible relationships

Based on the review of the literature, there appear to be three broad accounts concerning the extent to which spatial attention is involved in the benefit found for semantically related stimuli. To better understand the predictions made by these accounts, consider a hypothetical experiment involving two tasks. The first task is the report of two unrelated words in a word pair, one word presented above and one word below fixation, and the second task is the speeded detection of a probe that appears at the location of one of the two words. A related or neutral prime occurs at the center of the display on each trial. The related prime is related to one of the two words in the following word pair display and unrelated to the other word. The neutral prime is not related to either of the two words in the word pair. Additionally, an abrupt onset exogenous cue that is highly predictive of the probe's location appears on each trial. Thus, the probe will appear at the location of the spatial cue on most trials and also appear at the related word's location on half of those trials in which a related prime is presented.

The first account of the benefit found for semantically related stimuli is that spatial attention is oriented to the location of related versus unrelated stimuli. In other words, semantic attention operates through the allocation of spatial attention. According to this account, semantic relatedness is akin to the visual features of a stimulus in that semantically related stimuli are assumed to draw spatial attention much like stimuli with salient visual features do (e.g., Kim & Cave, 1995), even when those stimuli are task irrelevant (Theeuwes, 1992). Studies in the literature showing a greater number of eye fixations towards related than neutral distractors (e.g., Moores et al., 2003) are consistent with this account. Referring to the hypothetical experiment described in the previous paragraph, there are several outcomes that would support this account. First, a probe appearing at the location of a related cued word should be responded to faster, albeit only slightly so, compared to when a neutral prime is presented. In this situation, the spatial cue would have already directed spatial attention to the location where the probe will appear, and hence only a small benefit would be expected for probes appearing at the location of related cued words following related primes versus unrelated cued words following neutral primes. Second, consider the situation where the probe appears at the location of an uncued related word, that is the cue was invalid and the probe appears at the location previously occupied by a related word. Under this circumstance, the cost for the invalid spatial cue should be reduced compared to when the probe appears at the location of an unrelated word following a neutral prime. This pattern is expected because, according to this account, the related word would attract spatial attention to its location, and thus reduce the cost of the invalid cue. Finally, for valid cue trials, RT should be slower when the uncued word is related versus unrelated, again because the related word should attract some amount of spatial attention resources to its location. I will refer to this account for the relationship between semantic attention and spatial attention as the *spatial attention dependence* account.

The second account of the benefit found for semantically related stimuli states that related stimuli do not attract spatial attention, per se, but that compared to unrelated stimuli, spatial attention is slower to withdraw from their location. Benefit for the report of related stimuli is due to a non-spatial process, such as spreading activation (Collins & Loftus, 1975), but the cost to stimuli occurring at other locations is due to spatial attention's being delayed. This account is based on Stolz's (1996) findings, where words were used as spatial cues for a target discrimination task. Recall that while no benefit was found for valid related versus valid unrelated word cues, invalid word cues produced more cost when they were related than when they were unrelated. According to Stolz, cost occurs because the related words are more activated than unrelated words in a lexical or semantic system. This activation also influences a spatial system, such that the location of a related word is more activated than the location of an unrelated word, what Stolz calls a "location-semantic context." The extra activation for related words interferes with the process of disengaging spatial attention from that word's location. This account does not predict that the extra activation would cause related stimuli to attract spatial attention, only that spatial attention should be slower to disengage from a related versus unrelated stimulus once spatial attention has already been allocated to its location. Also, according to this account semantic and spatial attention do involve different resources (i.e., the benefit for related stimuli is not due to their attracting spatial attention). In the hypothetical experiment described earlier, this account predicts no benefit for probes appearing at the location of related cued words compared to unrelated cued words, because related words do not capture spatial attention: they just delay its disengagement. Similarly, there should be no difference for RTs to probes appearing at uncued related and uncued unrelated words. However, when the cue is invalid, RT to the probe should be slower when the cued word is related compared to when the cued word is unrelated, again because spatial attention should be slower to disengage from the cued related word than the cued unrelated word before moving to the probe's location. I will refer to this account for the relationship between semantic attention and spatial attention as the *delayed disengagement* account.

The third and final account of the benefit found for semantically related stimuli is that the limited capacity resources involved in semantic attention are independent of spatial attention. According to this account, the benefit and cost associated with the presence of related stimuli is due to their competing better than unrelated stimuli for the limited capacity resources associated with access to awareness because of their higher activation (Dark et al., 1996; Masciocchi & Dark, in revision). Spatial attention is required to read a word and process its meaning, (e.g., Lachter et al., 2004; McCann, Folk, & Johnston, 1992), and when there is spatial uncertainty as to the target word's location, spatial attention should be broadly focused over the display. Semantic attention entails increased activation in the semantic or lexical system and any benefit for processing semantically related words reflects something other than spatial attention. Behaviorally, no interaction between the presence of related words and spatial cues would be expected in the hypothetical experiment described above, a pattern that has been shown in the literature (e.g., Dark et al.; Stolz & Stevanovski, 2004). For instance, in the hypothetical experiment the benefit for probe responses on valid versus invalid cue trials should be similar regardless of whether the probe appeared at the location of a related word or unrelated word, indicating that spatial attention was not drawn to semantically related stimuli any more so than unrelated stimuli. This account is also consistent with Davenport and Potter's (2005) explanation for their results, which is that semantic relatedness biases responding towards stimuli conceptually related to a prime. I will refer to this account for the relationship between semantic attention and spatial attention as the *spatial attention independence* account.

Overview of Experiments

One difficulty with evaluating the existing research on the relationship between semantic attention and spatial attention is that the evidence supporting different explanations comes from different types of tasks. The best evidence that spatial and semantic attention involve the same set of limited capacity resources (i.e., the spatial attention dependence account) comes from eye tracking studies, which typically use displays containing four to eight stimuli, use a relatively easy task, use pictures displayed for an extended period of time, and repeat stimuli. Attention is measured via fixations, which can be dissociated from covert spatial attention. Conversely, studies that show the best evidence for two separate sets of limited capacity resources (i.e., the delayed disengagement and spatial attention independence accounts) typically use displays containing one or two target stimuli, use a relatively difficult task, use words presented under impoverished conditions, and do not repeat stimuli. Attention is measured by the type or number of stimuli that can be reported, which provides only indirect evidence as to where spatial attention is deployed in the display.

Thus, it is important to adopt a methodology in which the deployment of covert spatial attention can be measured while independently manipulating spatial and semantic effects on attention. To that end, the following procedure was developed. Trials began with a prime word, followed by a word display containing two or more words. The subjects' task was to indicate whether the prime word was presented in the word display, which it was on half the trials. On half the trials a word semantically related to the prime was also presented in the word display. The word display was preceded by a fixation display containing black bars to mask the onsets of the words, and thereby keep them from capturing spatial attention for that reason. Thus, at the onset of the word display, the bars essentially transformed into the word stimuli. This procedure is depicted in the top row of Figure 1 (labeled Experiment 1a).

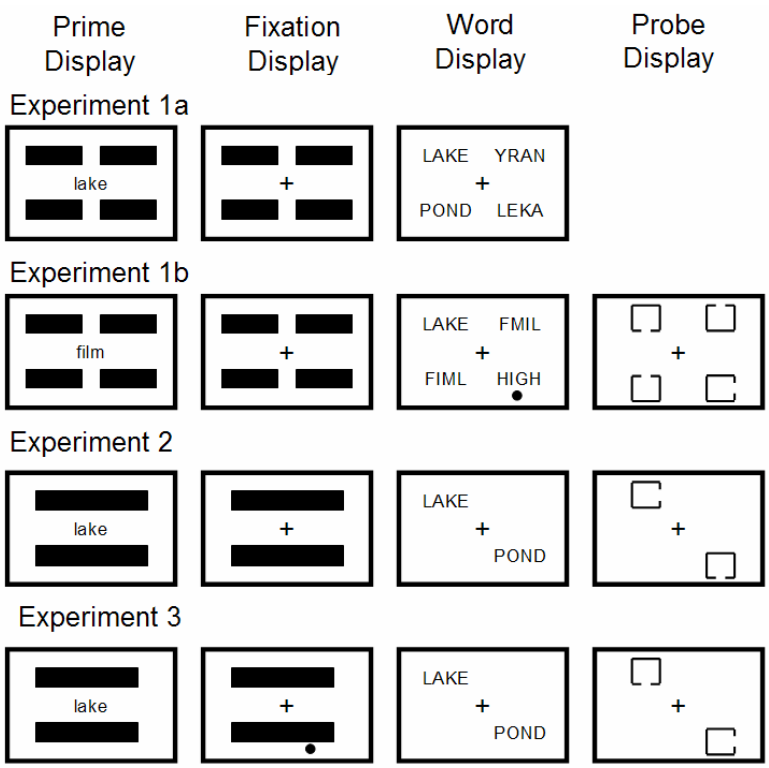

Figure 1. A depiction of a trial from each of the first three experiments.

In some experiments, to ascertain where spatial attention was directed within the word display, a probe display was presented. The probe display consisted of a probe target and one or more probe distractors that appeared at the location of each of the words in the word display. The subjects' task was to determine whether the probe target, a square with a gap on its side, had the gap on the left or right side. Distractor probes were squares with a gap on the top or bottom. Depending on the trial, the probe target could appear at the location of a word target, a related distractor, or an unrelated distractor. The probe task with the probe target at the location of the target in the word task is depicted in the third row of Figure 1 (labeled Experiment 2). Following the logic of LaBerge (1983) and Moores et al. (2003), it is assumed that responses in the probe task will vary as a function of where spatial attention is directed in the word display: Responses should be faster and more accurate when the probe appears at an attended location.[2] Thus, it should be possible to determine whether semantically related stimuli influence spatial attention by comparing RT and accuracy to the probe when it appears at the location of a word target, a related distractor or an unrelated distractor.

Experiment 1a was designed to explore whether the presence of a related distractor influences attention using this procedure. If so, then any failures in subsequent experiments to find differences in RT or accuracy or both on the probe task as a function of the location of a related distractor cannot be due to an unsuitable word task (i.e., a task that does not adequately influence semantic attention). In Experiment 1a the subjects' only task was to detect the presence or absence of the prime word in the word display as quickly and accurately as possible. Based on the results of previous research (Experiment 2, Moores et al., 2003; Meyer et al., 2007), responses were expected to be slower or less accurate or both when the related distractor was present. The first row of Figure 1 depicts a target present and related distractor present trial.

Experiment 1b was designed to determine whether the probe task is an effective technique for measuring the deployment of spatial attention in this procedure. The subjects' only task was to respond to the probe as quickly and as accurately as possible. The same displays as in Experiment 1a were used, except the prime was always unrelated and the probe display was added. Moreover, an abrupt onset (exogenous)[3] spatial cue or a central (endogenous) arrow cue appeared on some trials during the visual search display. When it appeared, the cue indicated the location where the probe target would appear in the probe display with 75% validity. Subjects did not perform the word task. Unrelated distractors were presented in the word display to preserve any visual masking of the probe, which would occur in subsequent experiments, while eliminating any effects of the related distractor in the word display. Based on previous research (Jonides, 1981; Posner et al., 1975; Posner, 1980; Yantis & Jonides, 1984), responses were expected to be faster or more accurate or both on valid cues trials compared to invalid cue trials. The second row of Figure 1 depicts a trial with a valid exogenous cue.

Subsequent experiments were designed to answer some unresolved questions. Experiment 2 investigated whether spatial attention is indeed captured by words semantically related to a prime. A similar procedure to Experiment 1a was used, and the probe task from Experiment 1b was added to assess where attention was deployed in the word display (see the third row of Figure 1). Experiment 3 was essentially a replication of Experiment 2 with the addition of an exogenous cue (see the fourth row of Figure 1). The purpose of this experiment was to investigate the effects of presenting semantically related stimuli and spatial cues in the same display. Finally, a different procedure was used in Experiments 4 and 5 to investigate the temporal processing of related and spatially cued words. A common aspect of many models of spatial attention (e.g., LaBerge & Brown, 1989; Stolz & Stevanovski, 2004) is the assumption that spatial attention speeds the processing of attended stimuli. Studies using the temporal order judgment paradigm have shown that when two stimuli are presented in close temporal proximity, including when they are presented simultaneously, the spatially attended stimulus is often judged to have occurred first (e.g., Stelmach & Herdman, 1991). Experiment 4 investigated whether related words would be judged as occurring sooner than unrelated words, and Experiment 5 was a replication of Experiment 4 with the addition of spatial cues.

CHAPTER 2. AN EXPERIMENT TO CONFIRM TASK SENSITIVITY

In much of this dissertation, a modified version of the probe detection task used by Moores et al. (2003) was employed to assess where subjects allocate spatial attention during a task in which they must decide whether a word presented at the start of the trial appears in a display containing two or more words. The following terminology will be used to describe the different components of this task. The word presented at the start of the trial will be referred to as the prime, which subjects were told was the target on that trial. The display in which subjects must decide whether the prime appeared will be referred to as the word display although it might contain nonword letter strings. When the prime occurs in the word display, it will be referred to as the target, and the trial will be referred to as a target present trial; if the prime does not occur, it will be referred to as a target absent trial. In Experiments 1a and 1b, all other stimuli in the word display will be referred to as distractors. On some trials a word that is semantically related to the prime will appear, and will be referred to as the related distractor. In Experiments 1a and 1b two of the stimuli in the word display were strings of letters, which will be referred to as nonwords. The display in which the probe appears will be referred to as the probe display, and the probe stimulus on which subjects will base their response will be referred to as the probe target. All other probes in the probe display will be referred to as probe distractors.

Experiment 1a was designed to confirm that the word task, which will be used in Experiments 2 and 3, is influenced by semantic attention. Experiment 1b was designed to confirm that the probe task, which will be used in Experiments 2 and 3, is a sensitive measure of where spatial attention is allocated. For example, consider a hypothetical result from Experiment 2, when the word task is presented with the probe task. A failure to find a difference for probes appearing at the location of related versus unrelated distractors could be due to: a) an insensitivity of the word task to semantic attention, b) an insensitivity of the probe task to spatial attention (as was the concern with Moores et al., 2003), or c) the fact that semantically related stimuli do not capture spatial attention as predicted by the spatial attention independence account. Given the possibility that such a result may be found, Experiment 1 was conducted in order to rule out the first two explanations.

In Experiment 1a, the prime and word displays were presented, and the subjects' only task was to decide whether the prime appeared in the word display. Previous studies have shown that RT and accuracy to make a target presence/absence response is impaired when a semantically related stimulus is present, particularly on target absent trials (Belke et al., 2008; Meyer et al., 2007; Moores et al., 2003). However, all these studies used pictures, and thus it is important to replicate this finding using words to insure that the findings generalize across stimuli.

In Experiment 1b, the prime, word and probe displays were presented, but the subjects' only task was to respond to the probe. All words in the word display were unrelated distractors. The goal of this experiment was to validate that the probe task is a sensitive measure of where spatial attention is allocated. Exogenous and endogenous spatial cues were used, in separate displays, to direct subjects' attention to the location where the probe target was likely to occur. The spatial cues were valid on most of the trials (75%). Based on numerous studies showing that endogenous and exogenous cues are effective at directing attention, an advantage for probe RT or accuracy or both was expected when the cues were valid versus when they were invalid. In other words, if the probe task is a sensitive measure of spatial attention, responses to the probe task should vary as a function of where spatial attention was allocated in the word display. Performance was also compared to a neutral cue condition to determine whether any observed differences were due to benefit for valid cues or cost for invalid cues or both.

Recall that Moores et al. (2003) examined responses to probes appearing at the location of targets and related stimuli. They used a luminance probe detection task, and subjects responded to whether the probe occurred on the left or right side of the display. No advantage was found for probes appearing at the locations of targets or related stimuli compared to those appearing at the locations of unrelated stimuli, which led the authors to argue that related stimuli do not attract spatial attention but instead influence a spatially invariant stage of processing. However, one drawback with their methodology is that determining the general location of a luminance probe might not be influenced by where spatial attention is allocated. As discussed earlier, abrupt onsets have been shown to capture attention automatically (e.g., Yantis & Jonides, 1990). The probe might have captured subjects' attention regardless of where they were attending in the search display. Also, detecting the location of the probe may not require the focusing of spatial attention on that location. Thus, the target or related stimulus may have drawn spatial attention, but probe responses might not have been affected by where spatial attention was allocated, which would explain the curious finding that no benefit was found for probes occurring at the location of the target. To avoid this potential problem, a probe target was used that requires the focusing of spatial attention on its location to make a correct response. Woodman and Luck (1999; 2003) showed that discriminating Landolt-C like targets produces serial-search like performance, indicating that the focusing of spatial attention is needed to perform the task. Thus, in Experiment 1b, subjects performed a probe discrimination task. They determined whether a probe target presented amongst distractor squares with gaps on their top or bottom had a gap on its left or right side.

Experiment 1a

The purpose of Experiment 1a was to confirm that the word task was influenced by the semantic relationship between primes and related distractors. The subjects' task was to decide whether the prime was presented in a word display containing two words and two nonwords. On half the trials, the prime (i.e., the target) was one of the two words in the display, and on half the trials one of the words was related to the prime. The rest of the words were unrelated distractors. This created four types of trials defined in terms of the types of words presented during the word display in addition to the two nonwords. Present-related trials consisted of the target and a related distractor. Absent-related trials consisted of a related distractor and an unrelated distractor. Present-unrelated trials consisted of the target and an unrelated distractor. Absent-unrelated trials consisted of two unrelated distractors.

Evidence of (involuntary) semantic attention capture would be found if performance on the word task differs when the related distractor is present versus absent. Based on previous studies (Belke et al., 2008; Meyer et al., 2007; Moores et al., 2003), target absent responses were expected to be slower or less accurate or both when the related distractor was present. Differences for target present trials are not typically found in the literature, but have been shown (Huettig & Altmann, 2005).

Method

Subjects. Twenty-four subjects were run in Experiment 1a. All had normal or corrected to normal vision, received research credit for participating from an introductory psychology course, and were native English speakers.

Stimuli and Equipment. Stimuli were presented using E-prime software (http://www.pstnet.com) on a 43 cm CRT Dell monitor with a viewing region of approximately 36.5 x 27.2 cm, a 1024 x 768 pixel resolution, and an 85 Hz refresh rate.

A total of 480 prime-associate pairs were selected from the Free Association Norms (Nelson, McEvoy & Schreiber, 1998). The associate[4] was selected for each prime so that it met the following criteria. It was one of the four highest associates with the prime, had a forward associated strength of at least .10, and was within two letters of the prime's length.

Across subjects counterbalancing insured that all words appeared equally often in all trial types and no word was ever repeated, except that the prime occurred in both the prime display and the word display on the target present trials. To meet the counterbalancing requirements, prime-associate pairs were divided into 80 sets of six pairs of words, with the restriction that all primes within a set were within one letter in length. Words were then selected within a set to form the different trial types, such that each of the 80 sets of six word pairs produced one of each of the four trial types. Using this arrangement, the 480 prime-associate pairs formed a total of 320 trials. An example of how this was accomplished is depicted in Table 1. To verbally describe this procedure, consider six hypothetical prime-associate pair: a1, a2, b1, b2… f1, f2, where '1s' are primes and '2s' are the corresponding associate. The words were re-arranged in the following manner to form the trial types: present-related = prime a1, search words a1, a2; absent-related = prime b1, search words b2, c2; present-unrelated = prime c1, search words c1, d2; absent-unrelated = prime d1, search words e1, f1. Finally, the six word-pairs within a set were placed in a different order for different subjects, such that the word-pair in position 'a' was shifted down to position 'f', and all other pairs were shifted up one spot. This procedure was performed five times total so that

Table 1. Example of how one of each of the four trial types was created from a set of six prime-associate pairs. Note that every associate appeared exactly once per subject.

	Words					
Word Type	a	b	c	d	e	f
Prime (1)	coal	fish	fork	swim	grass	noun
Associate (2)	miner	trout	spoon	pool	weed	verb

Trial Types	Creation of Trial Types		
Subject 1	Prime	Search Word 1	Search Word 2
Present-Related	coal (a1)	coal (a1)	miner (a2)
Absent-Related	fish (b1)	trout (b2)	spoon (c2)
Present-Unrelated	fork (c1)	fork (c1)	pool (d2)
Absent-Unrelated	swim (d1)	weed (e2)	verb (f2)
Subject 2			
Present-Related	fish (b1)	fish (b1)	trout (b2)
Absent-Related	fork (c1)	spoon (c2)	pool (d2)
Present-Unrelated	swim (d1)	swim (d1)	weed (e2)
Absent-Unrelated	grass (e1)	verb (f2)	miner (a2)

all primes and associates appeared equally often in all positions across subjects, and hence appeared equally often in all trial types.

The word display consisted of two words and two nonwords. These stimuli were presented at the corners of an imaginary rectangle centered on the fixation cross. The center of each word was approximately 3.1^{0} of visual angle from the fixation cross. The locations (top, bottom, left, right) of these words were counterbalanced across subjects such that each word was equally likely to appear at any location in the word display.

To prevent subjects from being able to perform the word task by using low-level visual characteristics of the prime and words in the word display (e.g., word length or first letter), two nonwords were presented along with the two words. Two different visually similar nonwords were created for each prime by rearranging the letters in the prime, except for the first letter.[5] Some nonwords were pronounceable while others were not. For target absent trials, each of the two nonwords derived from the prime were presented. For target present trials, one of the nonwords was derived from the prime and the other nonword was one of the nonwords created from re-arranging the letters of a different prime in the same set. Thus, on every trial there were always two stimuli (including the target on target present trials) that were visually similar to the prime because they had the same initial letter and number of letters as the prime.

For each trial the two stimuli that were visually similar to the prime were presented on one diagonal to insure that subjects were basing the target presence/absence decision on whether the prime was actually presented in the word display, and not on the number or location of stimuli that looked like it. On target present trials the (real) words were presented in the top and bottom positions in the same visual field to prevent any semantic processing differences that may have arisen from presenting the related distractor in the opposite visual field from the target. Thus, if the target appeared at the top-left position, the visually similar nonword appeared at the bottom-right position, the unrelated or related distractor appeared in the bottom-left position, and the nonword that did not look like the prime appeared in the top-right position. On target absent trials the (real) words were presented diagonally across from each other, and the nonwords, which both looked like the prime, were presented on the opposite diagonal. All prime-associate pairs and the nonwords derived from each prime are shown in the Appendix.

Procedure. An example of the procedure for each trial type is shown in Figure 2. Stimuli were presented in black on a white background. Each trial began with the word 'Ready' presented in the center of the screen for 1,500 ms, followed by a fixation cross

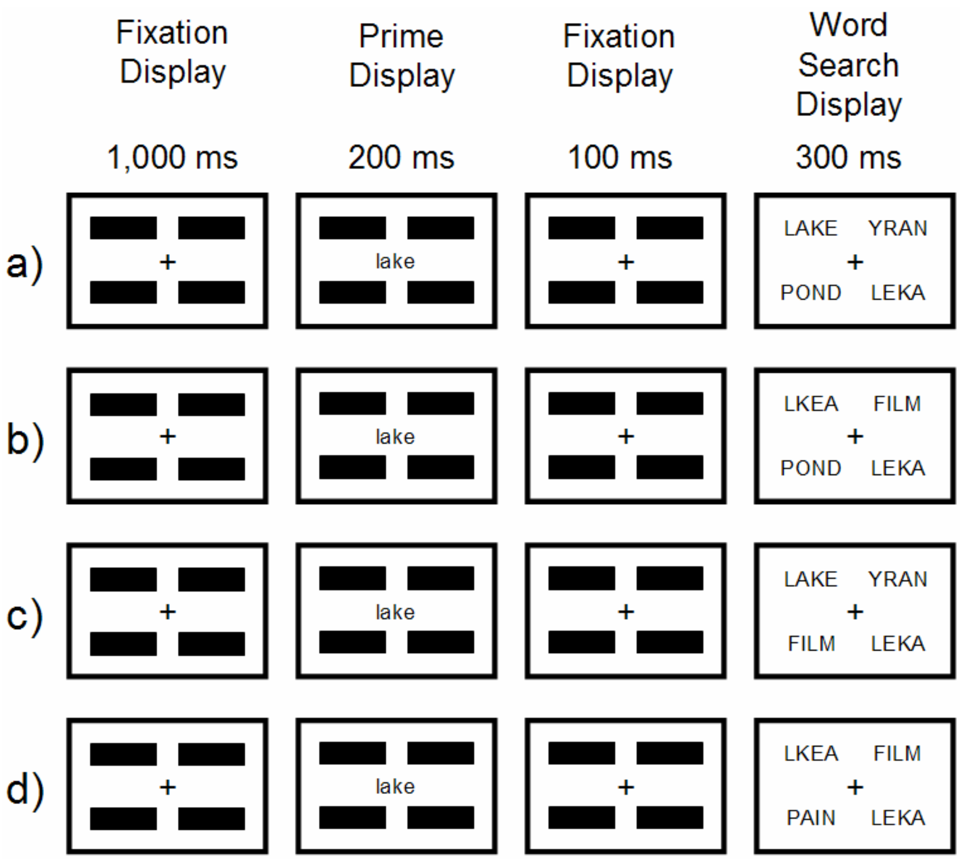

Figure 2. An example of the procedure and each of the four trial types in Experiment 1a: panel a) Present-related, panel b) Absent-related, panel c) Present-unrelated, panel d) Absent-unrelated.

and four black boxes with a width of approximately 5.3^0 and a height of approximately 1.0^0 presented at the corners of an imaginary rectangle approximately 3.1^0 from fixation for 1,000 ms. The boxes indicated where the words and nonwords would appear in the word display.

The boxes also served to mask the transient onset of the stimuli in the word display. Hence, they remained on the screen until the onset of the word display. The prime word, presented in lowercase letters, then replaced the fixation cross for 200 ms, and was followed by a second fixation cross for 100 ms which remained on the screen for the remainder of the trial. Next, the word display appeared. It consisted of two words and two nonwords, as described earlier. All stimuli in the word display were presented in capital letters at the previous location of the black boxes. Each letter subtended approximately 1.0^0 visual angle. The word display remained on for 300 ms, and then the words disappeared. Only the fixation cross remained. Subjects made an immediate speeded response by pressing the 'K' key if they believed the prime appeared in the word display and by pressing the 'L' key if they believed the prime did not appear in the word display. On each trial subjects received feedback on their accuracy.

The experiment consisted of 12 practice trials, and five blocks of 64 experimental trials, 16 of each trial type, for a total of 320 experimental trials. The entire experiment took approximately 40 minutes. Location of the words in the word display (top-left/bottom-right, top-right/bottom-left) and assignment of words into trial type was counterbalanced across subjects.

Results and Discussion

Unless otherwise stated all tests were evaluated with an alpha level of .05 two tailed. Actual p-values for each test are also provided. Analyses were run with both subjects (F_1 and t_1) and items (F_2 and t_2) as random factors (see Clark, 1973).

Accuracy. The means of the accuracy data for the four trial types are presented in Figure 3a. The data were examined using a 2 (target presence: present, absent) x 2 (related

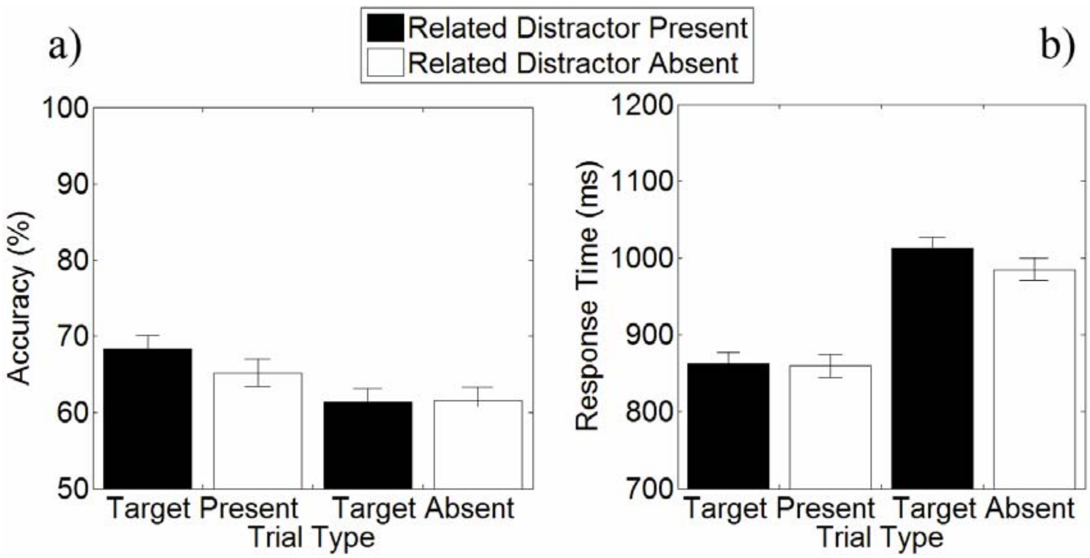

Figure 3. Mean accuracy (panel a) and RT (panel b) for the four trial types in Experiment 1a. Error bars are 95% within-subjects confidence intervals for the Target presence x Related distractor presence interaction (Loftus & Masson, 1994).

distractor presence: present, absent) analysis of variance (ANOVA). The main effect of target presence was marginally significant for subjects, $F_1(1, 23) = 3.85$, $MSE = 175.883$, $p = .06$, $\eta_p^2 = .14$, and significant for items, $F_2(1, 479) = 20.31$, $MSE = 667.185$, $p < .001$, $\eta_p^2 = .04$, as subjects were more accurate when the target was present (M = 68%) versus absent (M = 61%). The main effect of related distractor presence was marginally significant for subjects, $F_1(1, 23) = 4.08$, $MSE = 13.413$, $p = .06$, $\eta_p^2 = .15$, as subjects were more accurate when a related distractor was present (M = 65%) versus absent (M = 63%). However, the difference was not significant for items, $F_2(1, 479) = 1.97$, $MSE = 556.173$, $p > .15$. The interaction was not significant for subjects, $F_1(1, 23) = 2.38$, $MSE = 27.989$, $p = .14$, or items, $F_2(1, 479) = 1.96$, $MSE = 680.931$, $p = .16$. Because previous studies have found differences regarding the influence of related distractors for target present and absent trials, planned within-subjects t-tests examined whether accuracy on target present and target absent trials was influenced by the presence of related distractors. No significant difference was found for target absent trials for subjects, $t_1(23) = 0.10$, $SE = 1.51$, $p = .92$, or items, $t_2(479) = 0.10$, $SE = 1.64$, $p = .92$, although accuracy on present-related trials was higher than on present-unrelated trials for both subjects, $t_1(23) = 2.91$, $SE = 1.09$, $p < .01$, $\eta_p^2 = .18$, and items, $t_2(479) = 2.03$, $SE = 1.57$, $p = .05$, $\eta_p^2 = .01$. Thus, the presence of the related distractor did increase subjects' accuracy on target present trials.

RT. The RT data were examined using a similar ANOVA. That analysis included only correct responses that were within three standard deviations of each subject's mean. The trimming procedure removed fewer than 1.5% of trials on average per subject. The RT means for the four trial types are presented in Figure 3b. Words with missing data in a cell were excluded from the item analysis, which led to the exclusion of approximately 10% of the items. The ANOVA revealed a significant main effect of target presence for subjects, $F_1(1, 23) = 46.08$, $MSE = 9938.064$, $p < .001$, $\eta_p^2 = .67$, and items, $F_2(1, 433) = 168.96$, $MSE = 47180.540$, $p < .001$, $\eta_p^2 = .28$, as subjects were faster on target present (M = 861 ms) than target absent (M = 999 ms) trials. The main effect of related distractor presence was also significant for subjects, $F_1(1, 23) = 4.56$, $MSE = 457946.538$, $p = .04$, $\eta_p^2 = .17$, as subjects were overall slower to respond when the related distractor was present (M = 937 ms) versus absent (M = 922 ms). The main effect of related distractor presence was not significant with items, $F_1(1, 433) = 0.13$, $MSE = 46645.894$, $p = .72$. The Target presence x Related distractor presence interaction approached significance for subjects, $F_1(1, 23) = 2.91$, $MSE = 1226.438$, $p = .10$, $\eta_p^2 = 11$, but not items, $F_2(1, 433) = 1.63$, $MSE = 47425.091$, $p = .20$. Planned within-subjects t-tests for subjects only, because the interaction in the item analysis did not approach significance, examined whether reaction times on target present and target absent trials were influenced by the presence of a related word. No significant difference was found for target present trials, $t_1(23) = 0.35$, $SE = 8.28$, $p = .73$, however, on target absent trials RT was slower on absent-related trials than on absent-unrelated trials, $t_1(23) = 2.36$, $SE = 11.57$, $p = .03$, $\eta_p^2 = .20$. This difference cannot be accounted for by a speed-accuracy tradeoff, as accuracy was essentially identical in the absent-related (M = 61%) and the absent-unrelated (M = 62%) trial types.

The results of Experiment 1a showed that the presence of a related distractor influenced subjects' response on the word task when the target was present as well as when the target was absent. There are several potential explanations for this pattern. The first is that the related distractor may have biased subjects to make a target present response. When the target was present, subjects were more accurate at performing the search task, and when the target was absent the time to reject the presence of the target was slowed. A second explanation is that the target may have been easier to process when the distractor was related (e.g., Meyer & Schvaneveldt, 1971). Overall, the results generally replicate previous studies (e.g., Belke et al., 2008; Meyer et al., 2007; Moores et al., 2003) that found similar effects using objects rather than words, although the significant effect of related distractors on target present trials was somewhat novel (but see Huettig & Altmann, 2005). Therefore, if future experiments fail to show evidence that semantically related stimuli attract spatial attention, the results of Experiment 1a argue against the possibility that the null effect is due to insensitivity of the word task to semantic relatedness.

Not all differences found when subjects was the random effect were replicated in the item analysis. Most importantly, the interaction between related target presence and related distractor presence did not approach significance in the item analysis for the RT data. The difference between related distractor present and absent trials that is commonly reported in the literature was only significant in the subject analysis, and this may be due to the removal of many words from the item analysis because of missing data. While this lack of a difference is problematic, several changes made to the word task on subsequent experiments (see the next paragraph) alleviate the concern.

Accuracy on the word task was quite low, approximately 65%, despite the fact that subjects were making a binary decision and only had to make one response per trial. Such results show that on approximately 35% of trials the meaning of one or both words in the word display may not have entered awareness. In fact, the results of prior word naming studies (e.g., Dark et al., 1996; Masciocchi & Dark, in revision) also show that processing the meaning of words in briefly presented displays is a very difficult task. In subsequent experiments the question of interest is whether or not the meaning of a word influences spatial attention. However, if on a large number of trials the words in the word display are not being identified, or semantically processed, then one may not expect related distractors to influence spatial attention. As will be described in Experiment 2a, the word task was modified in an attempt to increase accuracy.

Experiment 1b

Experiment 1b was designed to rule out the other potential explanation for why there might be no relationship between semantic relatedness and spatial attention in future experiments, namely that the probe task is not a sensitive measure of where spatial attention is being allocated. To that end, exogenous and endogenous spatial cues were used to direct the subjects' spatial attention to specific locations in the probe display. On most trials (75%) the probe target appeared at the cued location (valid cue), however on some trials (25%) it appeared at the diagonally opposite location (invalid cue). If the probe task is an effective measurement of spatial attention allocation, then subjects should be faster or more accurate or both when the cue is valid versus invalid.

Method

Subjects. Eighteen subjects were run in Experiment 1b. All had normal or corrected to normal vision and received research credit from an introductory psychology course for participating.

Stimuli and Equipment. The stimuli and equipment for Experiment 1b were identical to those in Experiment 1a, with the following exceptions. In order to avoid any influences of semantic attention, all trials were absent-unrelated trials. This stipulation was accomplished by mixing the primes and associates within the same set described in Experiment 1a. The mixing procedure produced three absent-unrelated trials without repeating any words. Two lists were created so that subjects who saw each list saw different primes but the same absent-unrelated words, albeit in different pairs. Thus, as in Experiment 1a, all subjects saw all of the associates, although they were paired with different primes. For example, referring to Table 1, half of the subjects saw a1: b2, c2, c1: d2, e2, e1: f2, a2, on three different trials, while the other half of subjects saw b1: c2, d2, d1: e2, f2, f1: a2, b2. A total of 240 trials were generated in this manner. The re-arranged prime words (i.e., nonwords) also appeared in the word display, and were identical to those that appeared in Experiment 1a.

Exogenous and endogenous spatial cues signaled the location of the probe target with 75% validity. Exogenous cues consisted of a black circle with a diameter of approximately 0.8^0, presented approximately 1.1^0 above or below words appearing on the top or bottom, respectively, in the word display. Endogenous cues consisted of a black isosceles triangle (i.e., an arrow head) with a base of approximately 1.0^0 and a height of 1.5^0 presented at the center of the display pointing towards one of the four locations in the word display. The neutral cue consisted of the fixation cross remaining on screen for the duration of the word display without any additions to the display. Finally, four black squares, with a width and height of approximately 1.7^0, appeared following the word display 0.7^0 degrees above the center of the top and 0.7^0 degrees below the center of the bottom words in the word display. One of the squares, the probe target, had a 0.4^0 gap on its left or right side. The other squares had a 0.4^0 gap on the top or bottom. The probe target always appeared at the location of one of the words in the word display, and probe distractors always appeared at the locations of nonwords. In valid trials, the probe target appeared at the location indicated by the spatial cue. On invalid trials, the probe target appeared at the diagonally opposite location.

Procedure. The trial procedure is shown in Figure 4. The procedure for Experiment 1b was identical to that of Experiment 1a with the following exceptions. The exogenous cue was presented 100 ms after the onset of the word display for 100 ms so that it offset with the word display. The endogenous cue replaced the fixation cross 100 ms after the onset of the word display and also appeared for 100 ms. The probe display consisted of four black squares and appeared immediately after the offset of the word display. Subjects responded to the location of the gap in the probe target by pressing the 'K' key if it appeared on the left side, and the 'L' key if it appeared on the right side. Accuracy and RT were recorded for this response, and subjects received feedback on their accuracy. No response was made to words appearing the word display. Subjects were informed that the words and nonwords in the word display were important for subjects in different conditions but were irrelevant for them.

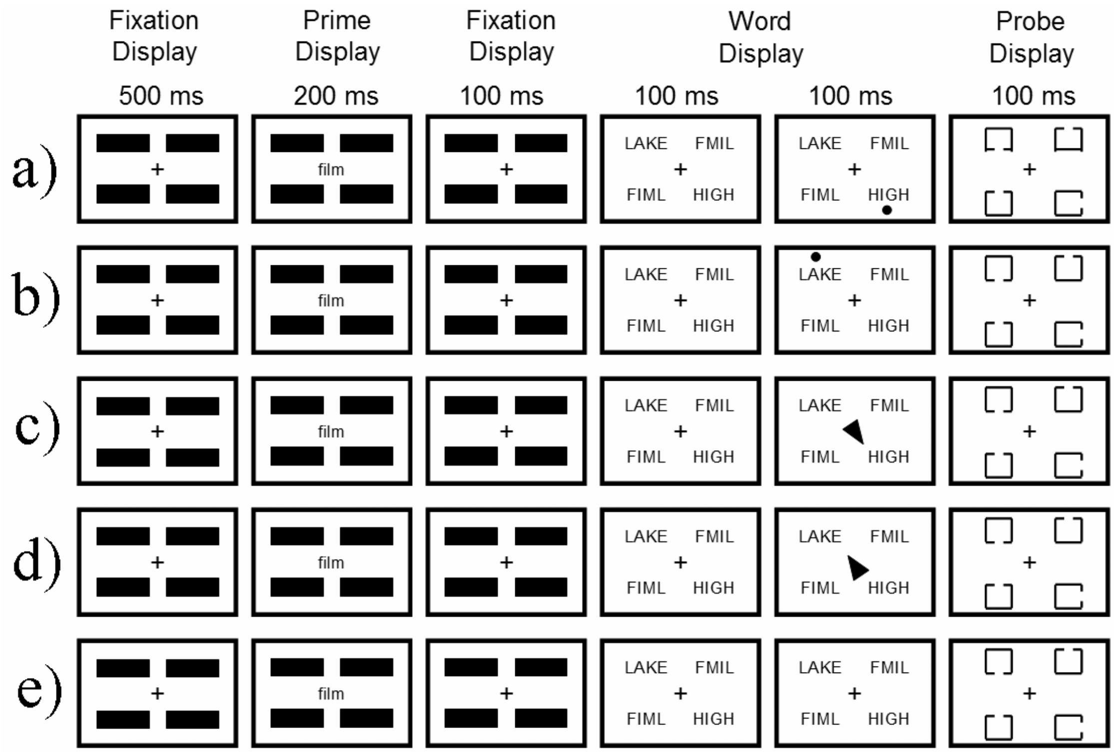

Figure 4. An example of the procedure and each of the five trial types in Experiment 1b: a) valid-exogenous, b) invalid-exogenous, c) valid-endogenous, d) invalid-endogenous, and e) neutral.

There were five trial types corresponding to the different cue types (see Figure 4): valid-exogenous cues, invalid-exogenous cues, valid-endogenous cues, invalid-endogenous cues, and neutral cues. The experiment was divided into five blocks of 48 trials, two blocks each of endogenous and exogenous cues, and one block of neutral cues, for a total of 240 experimental trials. Blocks with a particular cue type were always presented sequentially. Order of presentation was counterbalanced using a Latin-square design, such that one third of subjects began with the exogenous cues, endogenous cues, or neutral cues.

Results and Discussion

Because all trials contained only unrelated words that were task irrelevant, no item analysis was conducted.

Accuracy. Mean proportion correct for the exogenous and endogenous cue conditions are presented in Figure 5a. Mean accuracy in the neutral cue condition was 89.8% (SD = 10.3). A pair of within-subjects one tailed t-tests confirmed that valid cues produced more accurate responses than invalid cues for exogenous cues, $t_1(17) = 2.96$, $SE = 4.06$, $p < .01$, $\eta_p^2 = .34$, and endogenous cues, $t_1(17) = 2.20$, $SE = 3.66$, $p = .02$, $\eta_p^2 = 22$. Then to determine whether the differences were due to benefit and cost, all four types of cues were compared to the neutral cue using one tailed within-subjects t-tests. For the comparison between exogenous and neutral cues, no difference was found for valid-exogenous cues, $t_1(17) = 0.51$, $SE = 3.17$, $p = .30$, but responses following invalid-exogenous cues were less accurate, $t_1(17) = 2.87$, $SE = 3.63$, $p < .01$, $\eta_p^2 = .33$. For the comparison between endogenous and neutral cues, valid cues produced more accurate responses, $t_1(17) = 2.06$, $SE = 2.32$, $p = .03$, $\eta_p^2 = .20$, but there was no difference for invalid cues, $t_1(17) = 0.88$, $SE = 3.68$, $p = .20$.

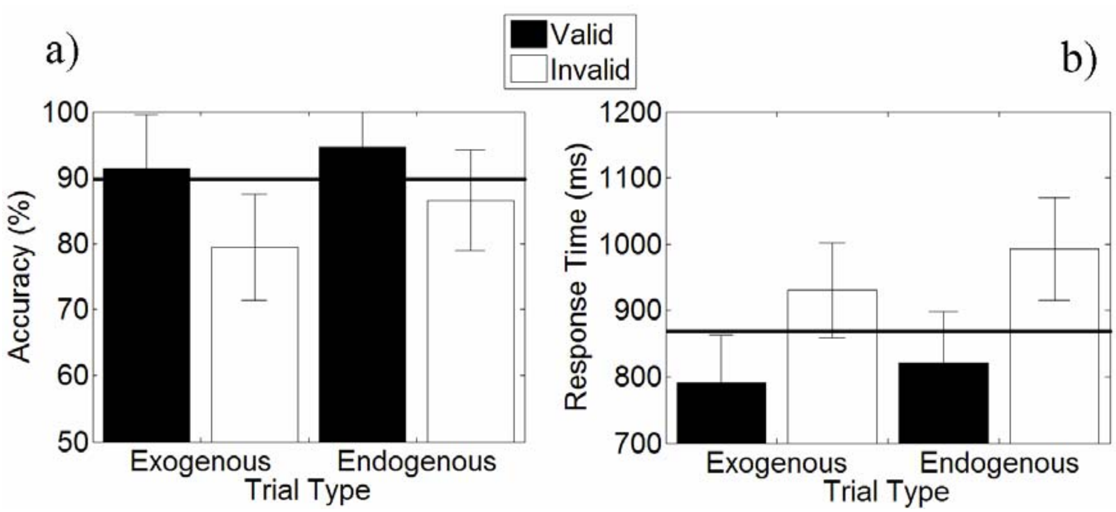

Figure 5. Mean accuracy (panel a) and RT (panel b) for the five trial types in Experiment 1b. Error bars are 95% within-subjects confidence intervals for the within-subjects t-test between valid and invalid trials for each cue type. The black line represents performance on the neutral cue condition.

RT. The RT data were examined using the same types of analyses. Only correct responses that were within three standard deviations of each subject's mean were included. The trimming procedure removed fewer than 1.5% of trials on average per subject. The RT means for the exogenous and endogenous cue trial types are presented in Figure 5b. Mean RT in the neutral cue condition was 868 ms (SD = 159). Valid-exogenous cues produced faster responses than invalid-exogenous cues, $t_1(17) = 4.07$, $SE = 34.36$, $p < .001$, $\eta_p^2 = .49$, and valid-endogenous cues produced faster responses than invalid-endogenous cues, $t_1(17) = 4.46$, $SE = 38.60$, $p < .001$, $\eta_p^2 = .54$. Comparing the exogenous cues to the neutral cues, a marginally significant difference was found for valid cues, $t_1(17) = 1.63$, SE = 47.45, p = .06, $\eta_p^2 = .14$, while invalid cues produced significantly slower responses, $t_1(17) = 1.81$, $SE = 34.70$, $p = .05$, $\eta_p^2 = .16$. Compared to neutral cues, no difference was found for valid-endogenous cues, $t_1(17) = 1.26$, $SE = 37.45$, $p = .12$, while invalid-endogenous cues produced significantly slower responses, $t_1(17) = 3.37$, $SE = 37.15$, $p < .01$, $\eta_p^2 = .40$. The patterns in the accuracy and RT data were very similar, and there was no indication of a speed-accuracy tradeoff.

The results of Experiment 1b showed that probe responses following valid cues were faster and more accurate overall compared to those following invalid cues for both cue types. Moreover, compared to the neutral cues condition, valid cues tended to produce faster and more accurate responses and invalid cues tended to produce slower and less accurate responses, although the differences were not always statistically significant. Overall, these results indicate that the types of cues chosen are effective at manipulating spatial attention and that the probe task was sensitive enough to pick up on this influence. Therefore, if in future experiments no evidence is found that semantically related stimuli do attract spatial attention, the results of Experiment 1b argue against the possibility that the null effect is because the probe task is an ineffective index of where spatial attention is being allocated in the word display.[6]

CHAPTER 3. PURE SEMANTIC INFLUENCES ON SPATIAL ATTENTION

Experiment 2a

There were two important findings from Experiment 1. First, in Experiment 1a the presence of a related distractor affected search performance when the task was to decide whether a target occurred in the word display. Second, Experiment 1b showed that the probe task was effective at measuring spatial attention. These two tasks were combined in Experiment 2a. Subjects searched for the prime target in the word display while also performing the probe task. The purpose of this experiment was to examine, in the absence of any explicit influences on spatial attention, whether stimuli semantically related to a prime capture spatial attention. Subjects responded to the probe task before making a target present/absent response to the word display, allowing both RT and accuracy to be recorded for the probe response. As shown in Experiment 1b, differences in probe responses can be manifested in RT or accuracy or both, and because Experiment 2a was primarily designed to investigate spatial attention it was important that both dependent variables were examined for the probe task. Furthermore, the location of the probe target was independent of the presence of or the location of the target or related distractor in the word display, and thus the capture of spatial attention by related stimuli should be unintentional. Finally, to insure that subjects were actively searching for the target word in the word display, on target absent trials a word that was visually similar to the target, which will be referred to as the target look-alike, was always present.

The three accounts described earlier would make the following predictions concerning the impact of a related distractor. While the same analyses will be conducted for target present and absent trials, the presence of the target may override any effects of the related distractor, so the predictions will only be presented for target absent trials. Although the focus is on probe task performance, the predictions of the three accounts must be understood in terms of concurrent performance of the two tasks. Subjects likely perform the word task by searching for the word that looks like the prime. At the onset of the word display, on most trials spatial attention should thus shift to the location of the target look-alike to discern whether that word is actually the target. The distractor may still influence performance, though attending to the distractor is unnecessary to perform either the word task or the probe task.

According to the spatial attention dependence account, the benefit found for semantically related stimuli is due to those words attracting spatial attention to their location. Although spatial attention is assumed to shift to the target look-alike as part of the word task, the related distractor should draw spatial attention to its location as well. Subjects should be faster or more accurate or both to respond to probes occurring at the location of related versus unrelated distractors. However, it would not be appropriate to directly compare responses to probes occurring at the location of a related versus unrelated distractor, as probe responses may be slower (or faster) simply because the related distractor was present, and not because it attracted spatial attention. This account thus predicts an interaction between probe location and related distractor presence. When the probe occurs at the location of the target look-alike, responses should be slower or less accurate when the distractor is related versus unrelated, and when the probe occurs at the location of the distractor, responses should be faster or more accurate when the distractor is related versus unrelated.

According to the delayed disengagement account, the benefit found for related stimuli is due to non-spatial processes, such as spreading activation, while the cost is due to a delay in disengaging spatial attention from the location of related stimuli. Related stimuli should not capture spatial attention on their own; the only stimulus that should capture spatial attention in the word display on target absent trials is the target look-alike. This account predicts that performance on the probe task should not differ as a function of whether the probe occurs at a related or unrelated distractor. A main effect of related distractor presence may be found, such that responses are slower or less accurate when the related distractor is present, but no interaction between related distractor presence and probe location should be found.

The delayed disengagement account makes an additional prediction concerning the difference between target absent and target present trials. Spatial attention is assumed to be attracted to both targets and target look-alikes as part of the word task. When the probe occurs at the distractor's location, a shift of attention would thus be required to identify it. According to the delayed disengagement account, however, shifting spatial attention away from the target word should be more difficult than shifting spatial attention away from the target look-alike. Thus, this account also predicts an interaction between target presence and probe location. The difference in RT or accuracy to probes appearing at the distractor versus the word that looks like the target (i.e., either the target or target look-alike) is expected to be larger on target present versus target absent trials.

According to the spatial attention independence account, the benefit for related stimuli is due to non-spatial processing. If this account is accurate, the location of a related distractor in the word display should have no impact on probe task performance. For instance, recall that Moores et al. (2003) failed to find a difference in responses to probes appearing at the location of related distractors compared to unrelated distractors. Other experiments in their paper did demonstrate, though, that related stimuli influenced performance on other tasks, such as increasing the total number of stimuli that could be reported in the search display. Similarly, Experiment 1a demonstrated that related distractors do influence performance on the word task. Thus, the predictions of the spatial attention independence account coincide with those of the delayed disengagement account regarding the impact of related distractors: The location of the related distractor should not influence performance on the probe task and there should not be any interaction between probe location and related distractor presence.

The presence of a related distractor may affect performance due to non-spatial processes, for instance by slowing probe responses when the related distractor is present. The time it takes subjects to respond to the probe is likely a combination of two decisions: whether the target is present or absent and the identity of the probe target. Word displays are presented for 150 ms and the probe display occurs immediately after. Subjects are likely still deciding whether the target was present when the probe display appears. Any effect that increases decision time on the word task, for instance the presence of a related distractor (Moores et al., 2003), may thus increase RT on the probe task. Therefore, an overall slowing on probe responses when the related distractor is present does not imply that the related distractor influences spatial attention and would be compatible with all three accounts.

Method

Subjects. Forty subjects were run in Experiment 2a. All had normal or corrected to normal vision, were native English speakers, and received research credit in an introductory psychology course for participating. Six subjects had an overall accuracy of less than 70% on the probe task or the word task and were replaced.

Stimuli and Equipment. The equipment was identical to that used in Experiments 1a and 1b. However, modifications were made to the word task in an attempt to increase accuracy.

In Experiment 1a, accuracy on the word task was quite low, as subjects were only correct on approximately 65% of the trials. Poor performance on the word task complicates interpreting any differences on the probe task. To make the word task easier, only two stimuli, both of which were real words, were presented in the word display. On target present trials, one word was the target and the other word was a distractor that was either related (present-related trial) or unrelated (present-unrelated trial) to the prime. On target absent trials, two distractors were presented. One distractor, the target look-alike, was always visually similar to the target word: It began with the same one or two letters as the prime, contained the same number of letters, and was matched as closely as possible to the prime on word frequency. This method was used to insure that subjects would have to actually read the words on target absent trials. They could not, for example, adopt a simple strategy of searching the first one or two letters of each word in the word display to determine whether the target was present. Thus, on each trial there was a word that was visually similar to the target. On target present trials this word was the target, and on target absent trials this was the target look-alike. The other distractor on target absent trials was either related (absent-related trial) or unrelated (absent-unrelated trial) to the prime. Words were always presented at opposite ends of an imaginary square centered on the fixation cross.

A total of 256 prime-associate pairs from Experiment 1a were used in Experiment 2a. Only primes that were six or fewer letters in length were used, and an attempt was made to choose those pairs with the highest forward association strength. The visually similar words were selected by using the English Lexicon Project (http://elexicon.wustl.edu/default.asp; see Balota et al., 2007) website based on those characteristics described previously. To perform the counterbalancing procedure, words were arranged into triplets: a prime (or target), an associate, and a target look-alike. The 256 word triplets were arranged into 64 sets of four triplets per set to produce one trial of each of the four trial types in much the same way as they were created in Experiment 1a (see Table 2 for an example of how this was accomplished). Counterbalancing insured that each prime, associate and look-alike occurred equally often in all trial types. The associates served as both the related and unrelated distractors. In related distractor trials, the associate was matched with its corresponding prime. In unrelated distractor trials, the associate was matched with a different prime within the same set. Primes, associates and target look-alikes were never repeated for a given subject.

The main question of interest is whether responses to the probe task are influenced by the location of the related distractor in the word display when the location of the related distractor and the location of the target is irrelevant for determining the location or identity of the probe. The probe target was equally likely to appear at the location of either word in the word display.

Procedure. The procedure was similar to that of Experiment 1a, with the following modifications. Only two words were presented in the word display, one centered above and one centered below fixation. The interstimulus interval between the prime display and word display was increased to 500 ms to try to increase the effect of the prime. To prevent subjects from making eye movements while the word display was presented, its duration was decreased to 150 ms and the distance between the center of the two words and the fixation

Table 2. Example of how one of each of the four trial types was created from a set of four triplets.

Word Type	a	b	c	d
Prime (1)	arm	girl	hay	old
Associate (2)	leg	boy	barn	new
Target Look-alike (3)	art	gave	ham	own

Trial Types	Creation of Trial Types		
Subject 1	Prime	Target/Look-alike	Distractor
Present-Related	arm (a1)	arm (a1)	leg (a2)
Present-Unrelated	girl (b1)	girl (b1)	new (d2)
Absent-Related	hay (c1)	ham (c3)	barn (c2)
Absent-Unrelated	old (d1)	own (d3)	boy (b2)
Subject 2			
Present-Related	girl (b1)	girl (b1)	boy (b2)
Present-Unrelated	hay (c1)	hay (c1)	leg (a2)
Absent-Related	old (c1)	own (c3)	new (d2)
Absent-Unrelated	arm (a1)	art (a3)	barn (c2)

cross was decreased to approximately 2.0^0 visual angle. The probe display was presented immediately after the offset of the word display for 70 ms. Only two squares were presented in the probe display, one approximately 1.5^0 above the center of the top word and one the same distance below the center of the bottom word. Subjects made a speeded response to the probe target (left or right gap in one square) prior to responding to whether the prime was present or absent in the word display. Using their right hands, they pressed the 'L' key to indicate that the probe target had a gap on the right side, and the 'K' key for the left side.

Subjects then used their left hands to make an unspeeded response to the word task by pressing the '1' key to indicate that the target appeared in the word display, and the '2' key to indicate that it was absent. At the end of each trial, subjects received feedback regarding their accuracy on both the probe and word tasks.

There were 256 experimental trials, divided into four blocks of 64 trials, as well as eight practice trials. The experiment took approximately 45 minutes. Location of the words in the word display and assignment of words into trial types was counterbalanced across subjects.

Results and Discussion

Word task. As described earlier, the only dependent variable for the word task was accuracy. A 2 (target presence) x 2 (related distractor presence) ANOVA was conducted to examine whether the related distractor influenced performance on the word task. The means are presented in Figure 6. The main effect of target presence was significant in subjects, $F_1(1, 39) = 5.93$, $MSE = 178.000$, $p = .02$, $\eta_p^2 = .13$, and items, $F_2(1, 255) = 41.70$, $MSE = 153.801$, $p < .001$, $\eta_p^2 = .14$, as accuracy was higher on target present (M = 87%) than target absent (M = 82%) trials. This difference was qualified by a significant Target presence x Related distractor presence interaction for subjects, $F_1(1, 39) = 36.08$, $MSE = 21.030$, $p < .001$, $\eta_p^2 = .48$, and items, $F_2(1, 255) = 28.88$, $MSE = 137.029$, $p < .001$, $\eta_p^2 = .10$. The presence of the related distractor improved performance on target present trials, $t_1(39) = 4.30$, $SE = .96$, $p < .001$, $\eta_p^2 = .32$, $t_2(255) = 3.85$, $SE = 0.91$, $p < .001$, $\eta_p^2 = .06$, but it impaired performance on target absent trials, $t_1(39) = 4.68$, $SE = .98$, $p < .001$, $\eta_p^2 = .36$, $t_2(255) = 3.85$, $SE = 1.13$, $p < .001$, $\eta_p^2 = .06$.

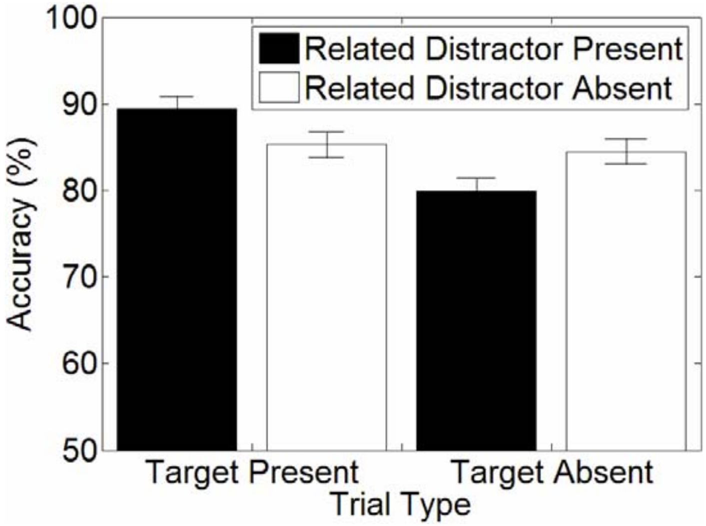

Figure 6. Mean accuracy on the word task in Experiment 2a. Error bars are 95% within-subjects confidence intervals for the Target presence x Related distractor presence interaction.

There are several possible explanations for this interaction. First, reading a word that was related to the prime may have biased subjects to respond "present" on the word task. This tendency would have lead to better performance on target present trials, when that response was correct, and poorer performance on target absent trials, when that response was incorrect, a pattern that mimics the data. Another possibility is that the related distractor may have influenced the interpretation of the other word in the word display. Meyer and Schvaneveldt (1971) showed that it is easier to process two related words presented together than a related and an unrelated word. Similarly, Schwarting and Johnston (1998) found that more words were reported in a word pair when those two words were related to each other. Thus, on target present trials, the target may have been better processed when the distractor was related, and on target absent trials the target look-alike may have been misinterpreted as the target when the distractor was related. However, the critical finding is that the word task was influenced by the presence of the related distractor, and thus the related distractor may have influenced the deployment of spatial attention. Performance on the probe task should reveal whether the related distractor influenced spatial attention. The fact that a similar pattern was found in the subject and item analyses is reassuring given that not all effects of the related distractor were replicated with items in Experiment 1a for the old version of the word task.

Probe task. Accuracy and RT data were examined separately, and the same analyses were conducted on both dependent variables. Only RTs for correct responses that were within three standard deviations of each subject's mean were examined. The trimming procedure removed fewer than 1.5% of trials on average per subject. Because the accounts may make different predictions for target present and target absent trials, these trials were examined separately as well. For the item analysis, words with missing data (approximately 4%) were excluded.

For target present trials, the data were examined using a 2 (related distractor presence) x 2 (probe location: target, distractor) ANOVA to determine whether responses to probes appearing at target versus distractor locations are influenced by the related distractor. The means are presented Figure 7. For the accuracy data, the only difference was a main effect of probe location, as accuracy was higher for probes occurring at target (M = 96%) versus distractor (M = 90%) locations for subjects, $F_1(1, 39) = 18.29$, $MSE = 70.243$, $p < .001$, $\eta_p^2 = .32$, and items, $F_2(1, 245) = 49.59$, $MSE = 209.240$, $p < .001$, $\eta_p^2 = .16$. A corresponding pattern was found in the RT data, with the only difference being a main effect of probe location for subjects, $F_1(1, 39) = 114.55$, $MSE = 14539.915$, $p < .001$, $\eta_p^2 = .75$, and items, $F_2(1, 245) = 158.88$, $MSE = 72320.433$, $p < .001$, $\eta_p^2 = .39$. Responses to probes occurring at targets were faster (M = 995 ms) than for probes at distractors (M = 1199 ms).

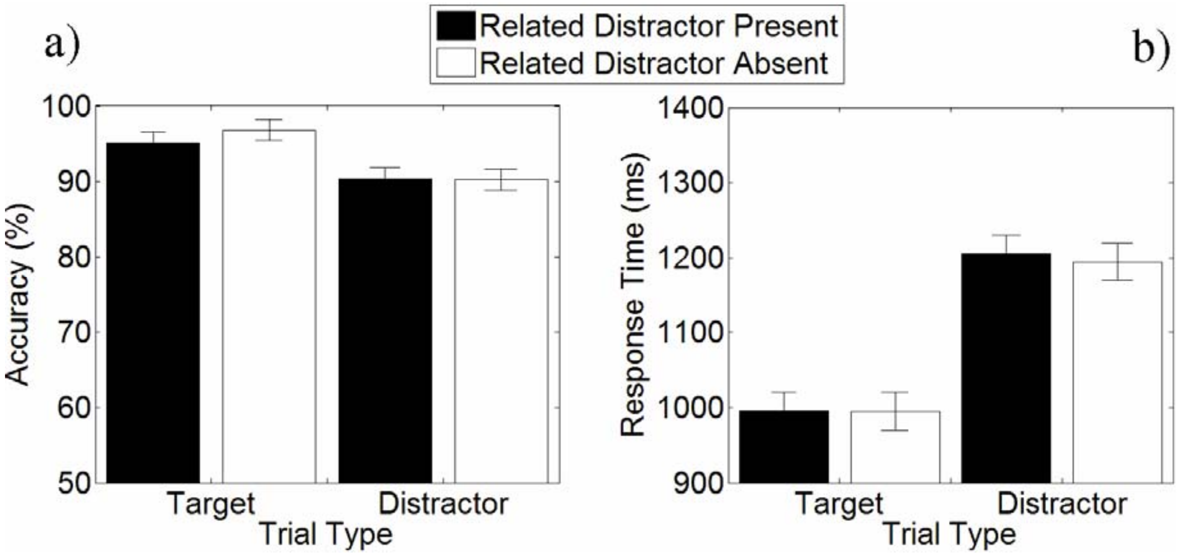

Figure 7. Mean accuracy (panel a) and RT (panel b) on the probe task in Experiment 2a for target present trials. Error bars are 95% within-subjects confidence intervals for the Probe location x Related distractor presence interaction.

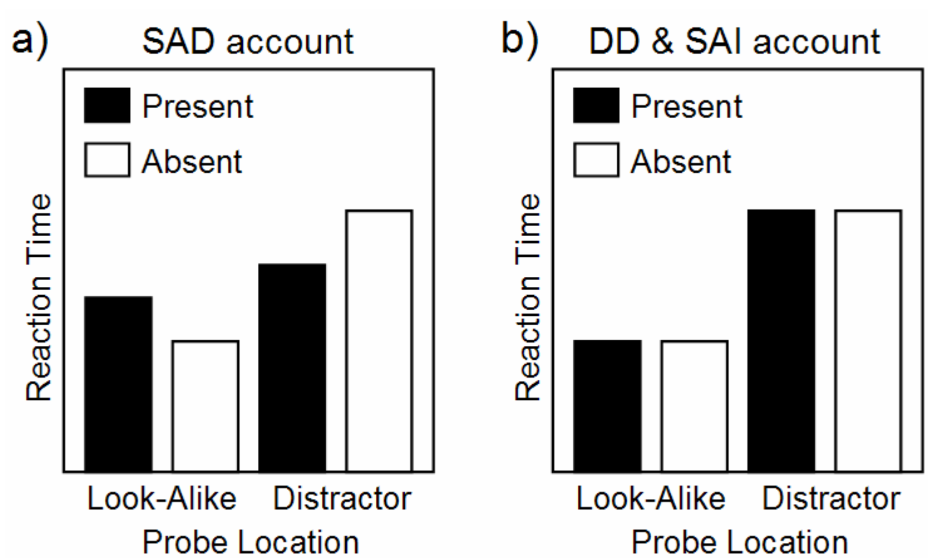

Figure 8. The predictions of (panel a) the spatial attention dependence account and (panel b) the delayed disengagement and spatial attention independence accounts. The graphs represent the Probe location (look-alike, distractor) x Related distractor presence (present, absent) interaction.

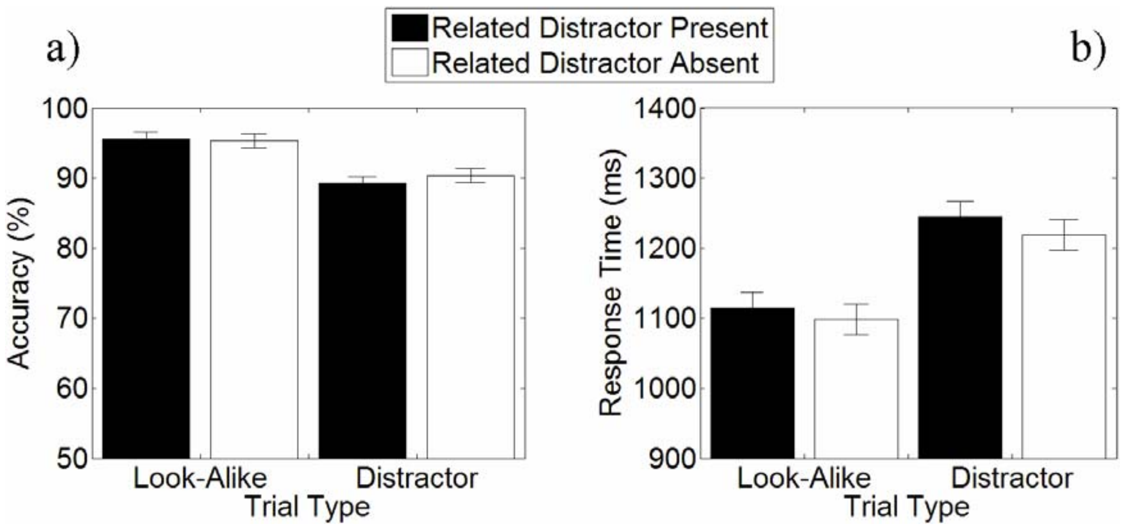

Figure 9. Mean accuracy (panel a) and RT (panel b) on the probe task in Experiment 2a for target absent trials. Error bars are 95% within-subjects confidence intervals for the Probe location x Related distractor presence interaction.

The predictions of the three accounts, which were verbally described earlier, are presented graphically in Figure 8. For target absent trials, a 2 (related distractor presence) x 2 (probe location: target look-alike, distractor) ANOVA was conducted to determine whether the presence of the related distractor influenced probe responses when the target was absent. For the accuracy data, which are presented in Figure 9a, the only significant difference was a main effect of probe location for subjects, $F_1(1, 39) = 23.51$, $MSE = 54.035$, $p < .001$, $\eta_p^2 = .38$, and items, $F_2(1, 255) = 33.08$, $MSE = 239.656$, $p < .001$, $\eta_p^2 = .15$, as accuracy was higher when the probe occurred at the location of the target look-alike (M = 96%) versus the distractor (M = 90%). The RT data are presented in Figure 9b. The main effect of probe location was significant for subjects, $F_1(1, 39) = 57.45$, $MSE = 10979.894$, $p < .001$, $\eta_p^2 = .60$, and items, $F_2(1, 245) = 17.17$, $MSE = 103233.418$, $p < .001$, $\eta_p^2 = .07$, as responses were faster when the probe occurred at the location of the target look-alike (M = 1107 ms) versus the distractor (M = 1232 ms). The main effect of related distractor presence was marginally significant for subjects, $F_1(1, 39) = 3.26$, $MSE = 5463.544$, $p = .08$, $\eta_p^2 = .08$, and significant for items, $F_2(1, 245) = 4.35$, $MSE = 84972.237$, $p = .04$, $\eta_p^2 = .02$, as RTs were slower when the related distractor was present (M = 1180 ms) versus absent (M = 1159 ms).

The main effect of probe location for accuracy and RT shows that probe responses were faster and more accurate when the probe occurred at the location of the target on target present trials or the target look-alike on target absent trials. This difference, which was significant for both subjects and items, suggests that the target and the target look-alike attracted spatial attention. The finding that the target look-alike attracts attention is not surprising. The subjects' task was to determine whether or not a target was present, and they likely performed the task by searching for the visually similar word. Studies that record use fixations as a measure of spatial attention have also found that visually similar objects attract spatial attention (e.g., Dahan & Tanenhaus, 2005; Huettig & Altmann, 2007; Huettig & Hartsuiker, 2008).

Recall that Moores et al. (2003), quite surprisingly, failed to find that pictures of target stimuli attracted spatial attention as indexed by their probe task. As discussed previously their probe task was a detection task, where subjects simply determined whether a black circle appeared on the right versus the left side of the display. The probe task employed in this dissertation was designed to be a more sensitive measure of spatial attention. The fact that an advantage was found for probes occurring at target locations indicates that this probe task is indeed a more effective measure of spatial attention.

Turning to the predictions of the three accounts, the main effect of related distractor presence in the RT data for target absent trials in the subject and item analyses shows that the related distractor did influence probe response. However, it did not interact with probe location, and probe responses were slower rather than faster on related distractor present trials. The results are best explained by an overall slowing on probe responses when the related distractor was present rather than by related distractors influencing spatial attention. This pattern was also shown by Moores et al. (2003) and is consistent with all three accounts.

The lack of a significant interaction between related distractor presence and probe location for target present or target absent trials, however, is inconsistent with the predictions of the spatial attention dependence account. An interaction was predicted because the difference between responses to probes occurring at target versus distractor locations was expected to be smaller when the related distractor was present versus absent. The delayed disengagement and spatial attention dependence accounts did not predict an interaction for either target present or absent trials. While it is difficult to interpret the meaning of a null result, the failure to find the expected interaction provides preliminary evidence against the spatial attention dependence account.

The delayed disengagement account predicted that spatial attention should be slower to disengage from target versus target look-alike words. In the RT data there was in fact a significant Target presence x Probe location (visually similar prime word, distractor) interaction for subjects, $F_1(1, 39) = 16.10$, $MSE = 3826.500$, $p < .001$, $\eta_p^2 = .29$, and items, $F_2(1, 245) = 25.96$, $MSE = 40810.397$, $p < .001$, $\eta_p^2 = .10$. The difference between RTs to probes appearing at the distractor versus the target location was larger (M = 204 ms) than the difference between probes appearing at distractor versus the target look-alike word (M = 126 ms). In other words, subjects were slower to disengage spatial attention from targets versus target look-alikes. This result suggests that delayed disengagement can occur, albeit only for target words, and that the probe task is capable of detecting such a difference.

In Experiment 2a, the item analyses corresponded with the subject analyses. The similar patterns show that the effects are not caused by differences on a small number of items. While there were no discrepancies in Experiment 2a, there were some discrepancies in Experiment 1a. There are two possible reasons for this difference. First, there were fewer excluded trials because of missing data in Experiment 2a, and second, only a subset of prime-associate pairs from Experiment 1a, pairs that tended to have a higher forward association strength, were used. Thus, the items used in Experiment 2a appear to be more appropriate than those used in Experiment 1a.

Overall, Experiment 2a provides initial evidence that semantically related distractors do *not* attract spatial attention. The failure to find that related distractors attract spatial attention goes against the spatial attention dependence account, but it is consistent with the null predictions of both the delayed disengagement and spatial attention independence accounts. Because the research strategy is to pit the three accounts against each other, the failure to find support for the spatial attention dependence account in Experiment 2a provides indirect support for the delayed disengagement and spatial attention independence accounts. While this conclusion is partially based on a null result, the probe task was clearly sensitive enough to detect a benefit for probes appearing at the location of targets, as well as an overall slowing when the related distractor was present on target absent trials. The presence of the related distractor also influenced performance in the word task. At this point the support is for the delayed disengagement and spatial attention independence accounts. Moreover, the finding that spatial attention was slower to disengage from targets versus target look-alikes, both of which appeared to attract spatial attention, provides additional support for the delayed disengagement account.

Experiment 2b

One of the more intriguing results of Experiment 2a was that on target absent trials subjects were faster and more accurate on probe responses when the probe occurred at the location of target look-alikes. The pattern essentially mimicked that for probes occurring at the location of targets in target present trials. Also, although the presence of the related distractor slowed RTs overall for target absent trials, there was no indication that the related distractor attracted spatial attention. One possible reason for the failure to find an effect, then, may be that the influence from the target look-alike overrode any spatial capture from the related distractor, just as may be expected for targets on target present trials. Given that the subjects' task was to search for words that were similar to the target, they likely adopted a strategy of attending to the word that began with the same few letters as the target.

To test whether the presence of the target look-alike may have interfered with the effect of the related distractor on spatial attention, Experiment 2a was replicated except that on target absent trials neither word was visually similar to the target. The target look-alikes were paired with different primes, so on target absent trials there were either two unrelated distractors or one related and one unrelated distractor. The related distractor should capture spatial attention according to the spatial attention dependence account. Thus, Experiment 2b provided a best-case-scenario test for capture of spatial attention by semantically related distractors in the absence of any overt influences on spatial attention.

Method

Subjects. Forty subjects were run in Experiment 2b. All had normal or corrected to normal vision, were native English speakers, and received research credit in an introductory level psychology course for participating. One subject had an overall accuracy of less than 70% on the probe task and was replaced.

Stimuli and Equipment. The stimuli and equipment were identical to those used in Experiment 2a with the following exception. The same words from Experiment 2a were also used in Experiment 2b, except they were paired differently on target absent trials. Table 3 demonstrates the counterbalancing procedure used in Experiment 2b.

Table 3. Example of how one of each of the four trial types was created from a set of four triplets.[7]

	Words			
Word Type	a	b	c	d
Prime (1)	arm	girl	hay	old
Associate (2)	leg	boy	barn	new
Target Look-alike (3)	art	gave	ham	own

Trial Types	Creation of Trial Types		
Subject 1	Prime	Target/Look-alike	Distractor
Present-Related	arm (a1)	arm (a1)	leg (a2)
Present-Unrelated	girl (b1)	girl (b1)	new (d2)
Absent-Related	hay (c1)	own (d3)	barn (c2)
Absent-Unrelated	old (d1)	art (a3)	boy (b2)
Subject 2			
Present-Related	girl (b1)	girl (b1)	boy (b2)
Present-Unrelated	hay (c1)	hay (c1)	leg (a2)
Absent-Related	old (c1)	art (a3)	new (d2)
Absent-Unrelated	arm (a1)	gave (b3)	barn (c2)

Target look-alikes were matched with different primes. These words were always unrelated to the prime and thus functioned as unrelated distractors. For data analysis purposes, as well as for ease of comparison to Experiment 2a, these words will continue to be referred to as target look-alikes. Primes, associates and target look-alikes were never repeated for a given subject.

Procedure. The procedure was identical to that of Experiment 2a.

Results and Discussion

The same analyses were conducted in Experiment 2b as in Experiment 2a, and the same trimming procedures were used, which lead to the average removal of fewer than 2% of the trials per subject, and approximately 2% of words in the item analysis.

Word task. The means for performance on the word task are presented in Figure 10.

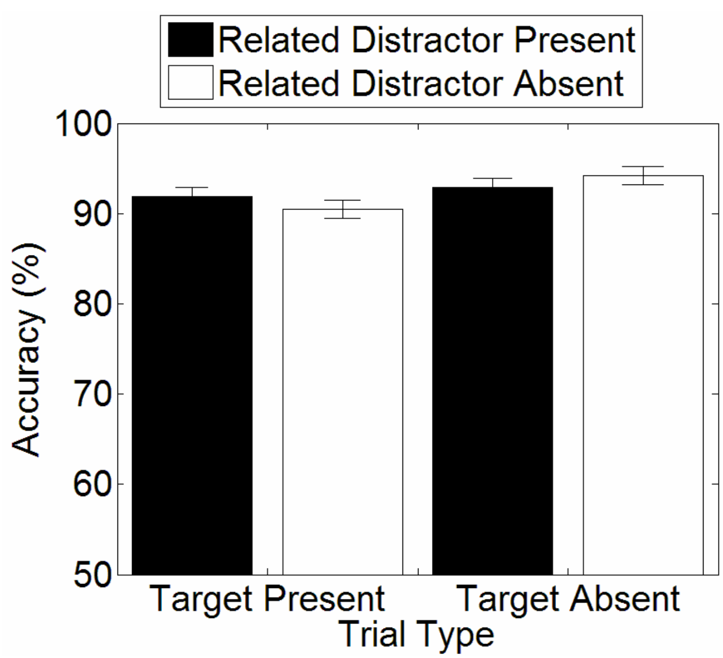

Figure 10. Mean accuracy on the word task in Experiment 2b. Error bars are 95% within-subjects confidence intervals for the Target presence x Related distractor presence interaction.

A marginally significant effect of target presence showed that accuracy was higher when the target was absent (M = 94%) versus when it was present (M = 91%) for subjects, $F_1(1, 39) = 3.39$, $MSE = 65.902$, $p = .07$, $\eta_p^2 = .08$. The effect was significant for items, $F_2(1, 255) = 23.01$, $MSE = 70.822$, $p < .001$, $\eta_p^2 = .08$. This effect was qualified by a Target presence x Related distractor presence interaction for subjects, $F_1(1, 39) = 6.80$, $MSE = 11.315$, $p = .01$, $\eta_p^2 = .15$, and items, $F_2(1, 255) = 7.11$, $MSE = 83.770$, $p < .01$, $\eta_p^2 = .03$, which was similar to Experiment 2a. Subjects were more accurate on target present trials when the related distractor was present (M = 92%) versus absent (M = 90%), $t_1(39) = 2.14$, $SE = 0.68$, $p = .05$, $\eta_p^2 = .11$, $t_2(255) = 1.68$, $SE = 0.86$, $p = .10$, $\eta_p^2 = .01$, and less accurate on target absent trials when the related distractor was present (M = 93%) versus absent (94%), $t_1(39) = 2.01$, $SE = 0.66$, $p = .05$, $\eta_p^2 = .09$, $t_2(255) = 2.29$, $SE = 0.70$, $p = .03$, $\eta_p^2 = .02$. Thus, the presence of the related distractor once again influenced performance on the word task, albeit to a much smaller extent than it did in Experiment 2a.

Probe task. The data for target present trials are presented in Figure 11. Accuracy on the probe task was higher when the probe occurred at target (M = 98%) versus the distractor (M = 94%) location for subjects, $F_1(1, 39) = 10.97$, $MSE = 58.895$, $p = .002$, $\eta_p^2 = .22$, and items, $F_2(1, 255) = 34.74$, $MSE = 138.137$, $p < .001$, $\eta_p^2 = .12$, and accuracy was lower when the related distractor was present (M = 96%) versus absent (M = 97%) for subjects, $F_1(1, 39) = 4.19$, $MSE = 7.213$, $p = .05$, $\eta_p^2 = .10$, and items, $F_2(1, 255) = 3.11$, $MSE = 140.133$, $p = .08$, $\eta_p^2 = .01$. A corresponding pattern was found in the RT data. Probe responses were faster for probes occurring at the target (M = 988 ms) versus distractor (M = 1178 ms) locations for subjects, $F_1(1, 39) = 120.12$, $MSE = 12050.569$, $p < .001$, $\eta_p^2 = .76$, and items, $F_2(1, 250) = 175.94$, $MSE = 49374.485$, $p < .001$, $\eta_p^2 = .41$. However, while there was a trend for subjects

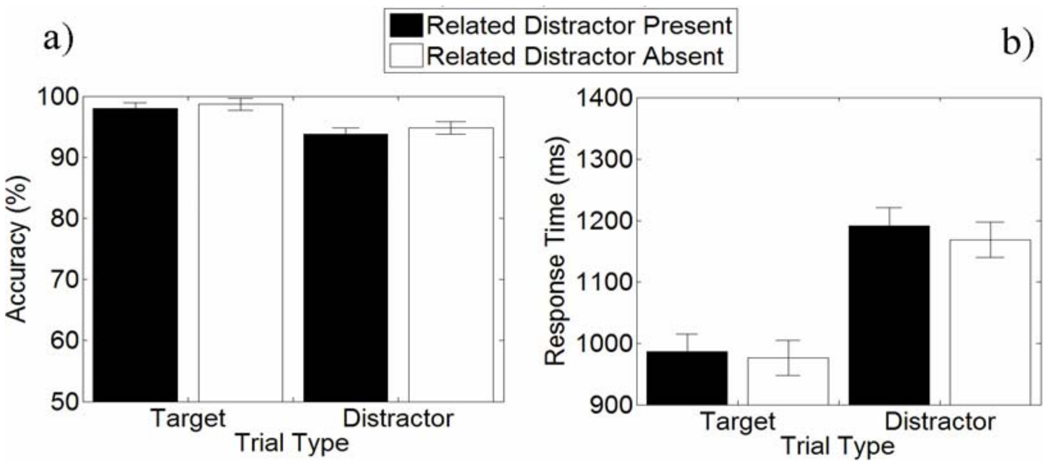

Figure 11. Mean accuracy (panel a) and RT (panel b) on the probe task in Experiment 2b for target present trials. Error bars are 95% within-subjects confidence intervals for the Probe location x Related distractor presence interaction.

to be slower when the related distractor was present (M = 1095 ms) versus absent (M = 1077 ms) the difference did not reach statistical significance for subjects, $F_1(1, 39) = 2.34$, MSE = 3130.737, $p = .13$, or items, $F_2(1, 250) = 1.00$, MSE = 51348.557, $p = .32$.

The predictions of the three accounts for the target absent trials are presented graphically in Figure 12. Only the spatial attention dependence account predicts an interaction between related distractor presence and probe location. The data for target absent trials are presented in Figure 13. For accuracy data, there was a main effect of related distractor presence for subjects, $F_1(1, 39) = 5.57$, MSE = 12.773, $p = .02$, $\eta_p^2 = .13$, and a non-significant trend for items, $F_2(1, 250) = 2.68$, MSE = 143.654, $p = .12$. Accuracy was lower when the related distractor was present (M = 96%) versus when it was absent (M = 97%). For RT data, there was a main effect of related distractor presence for subjects, $F_1(1, 39) = 25.35$, MSE = 2568.366, $p < .001$, $\eta_p^2 = .39$., and items, $F_2(1, 250) = 5.77$, MSE = 54317.512, $p = .02$, $\eta_p^2 = .02$. Responses were slower when the related distractor was present (M = 1134 ms) versus when it was absent (M = 1093 ms). No other differences were reliable.

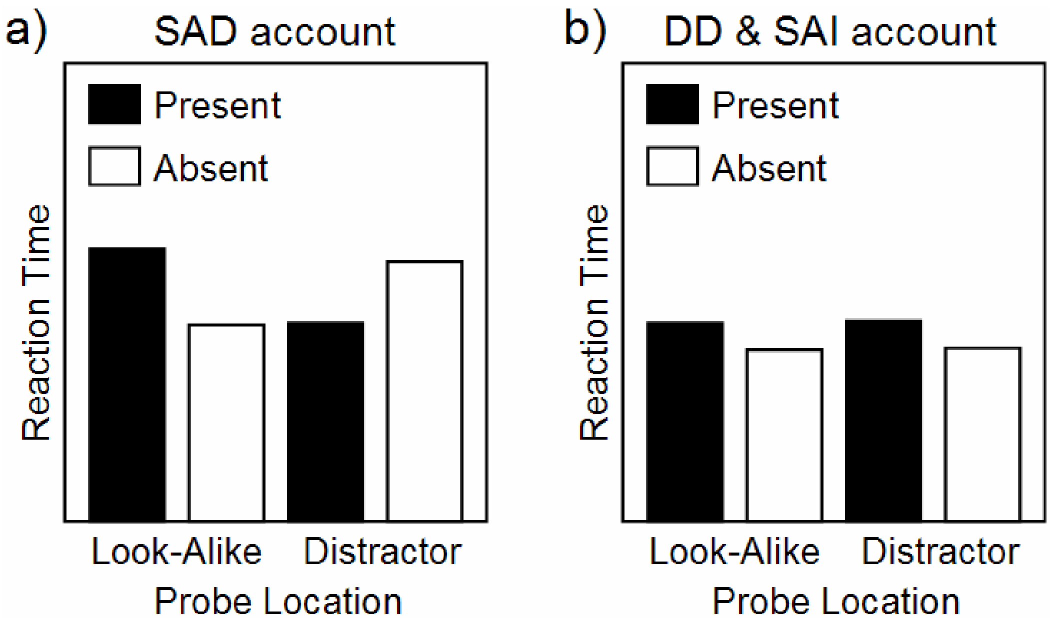

Figure 12. The predictions of (panel a) the spatial attention dependence account and (panel b) the delayed disengagement and spatial attention independence accounts. The graphs represent the Probe location (look-alike, distractor) x Related distractor presence (present, absent) interaction.

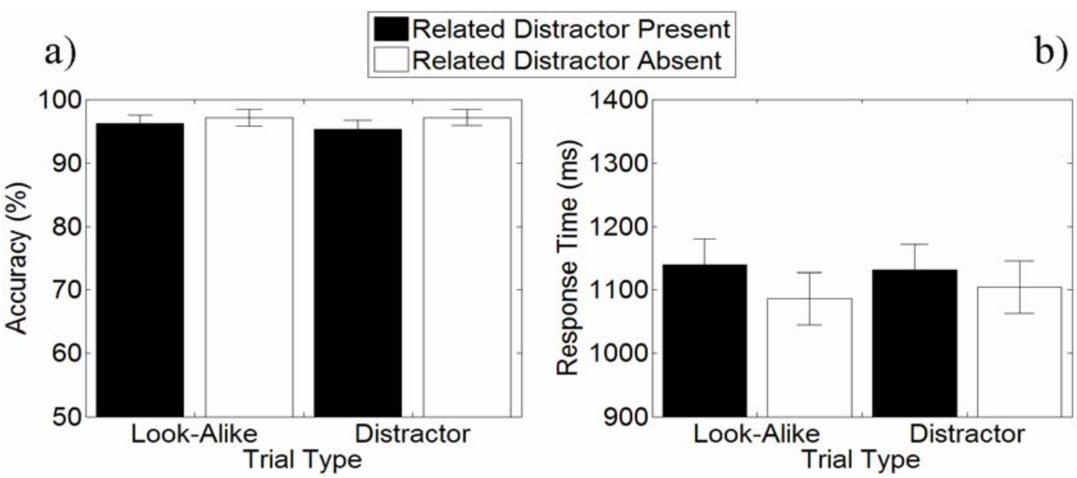

Figure 13. Mean accuracy (panel a) and RT (panel b) on the probe task in Experiment 2b for target absent trials. Error bars are 95% within-subjects confidence intervals for the Probe location x Related distractor presence interaction.

The results from Experiment 2b largely replicated those from Experiment 2a for the target present trials. The one main difference is that subjects were now less accurate when the distractor was related versus unrelated, and they also showed a non-significant trend to be slower. The related distractors likely were more salient in Experiment 2b due to the changes on target absent trials, which could account for these differences in results. The main finding, however, was that there was no interaction with probe location. The results confirm that related distractors were not capturing spatial attention. As with the target absent trials in Experiments 2a and 2b, the direction of the effect was also opposite of that predicted by the spatial attention dependence account for probes occurring at distractor locations, although it did replicate the findings of Moores et al (2003). The differences in the subject analysis were largely replicated in the item analysis.

The main effect of related distractor presence in the RT data for target absent trials generally replicated the results of Experiment 2a in that there was no indication that the semantically related distractor attracted spatial attention when it was present. The conditions in Experiment 2b, in which there was no target look-alike on target absent trials, offer the best case scenario for finding that semantically related distractors capture spatial attention. The concern that subjects were not reading the words and thus should not be influenced by the related distractor is lessened by the significant main effect of related distractor presence: If subjects were not reading the words, then related distractors should never affect probe responses. Instead, related distractors simply do not appear to attract spatial attention. Together, the results of Experiments 2a and 2b provide strong evidence against the spatial attention dependence account.

CHAPTER 4. SEMANTIC AND SPATIAL INFLUENCES ON ATTENTION

Experiment 3

Experiment 2 showed that related distractors do not capture spatial attention any more than do unrelated distractors. In many situations where the semantic meaning of a stimulus is important, though, there likely are other factors present that will influence spatial attention. It could be that semantic relatedness has an impact on spatial attention under situations in which spatial attention is being influenced in other ways. In order to test this possibility, Experiment 3 examined the allocation of spatial attention when semantically related distractors and exogenous spatial cues were presented in the same display. The addition of a spatial cue is a novel manipulation in that neither Moores et al. (2003) nor Belke et al. (2008) nor Meyer et al. (2007) examined the concurrent influences of spatial and semantic effects on the speeded search for a target. The closest approximation in the literature of which I am aware is Stolz (1996), who used related or unrelated words as abrupt onset spatial cues. However, because the spatial cue was also the related stimulus, Stolz was unable to examine the outcome of having a related stimulus and a cued stimulus appear at separate locations.

The purpose of Experiment 3 was to examine whether probe responses were influenced by the location of the related distractor and the exogenous spatial cue. As in Experiment 2, subjects searched for the target in the word display and then immediately performed the probe task before making their response to the word task. The spatial cue was used to direct spatial attention to the location of one of the words in the word display, and unlike Experiment 1b it occurred prior to the onset of the word display. The cue served as an irrelevant exogenous cue for the word task and a relevant endogenous cue for the probe task because it predicted the location of the probe target in the probe display with 75% validity.

Subjects should presumably use the cue to prepare for the probe task. The spatial cue was not predictive of whether the target (or the related distractor) occurred in the word display, or where it occurred when it was present. However, because exogenous spatial cues have been shown to attract attention in an obligatory manner (Yantis & Jonides, 1984; 1990), particularly when the location of a target is uncertain, spatial attention should be directed to the cued word at the onset of the word display.

All three accounts make different predictions, which are described for target absent trials only because the strongest effects should be found on those trials. The predictions of the three accounts must again be understood in terms of subjects also performing the word task. Experiment 2a showed that subjects direct spatial attention to the target look-alike as if it were the target, suggesting that on the word task subjects are indeed searching for words that look like the prime. As a result, the allocation of spatial attention should be the result of two factors: the location of the target look-alike and the location of the spatial cue. For the word task on target absent trials, spatial attention should shift to the location of the target look-alike to help discern whether that word is the target, regardless of whether that word is cued. Spatial attention should then shift to the location of the cue to maximize performance on the probe task. So, when the target look-alike is also cued, spatial attention should be directed exogenously to the location of that word via the spatial cue and it should remain there because the cue also predicts the location of the probe. The distractor may still influence performance, though attending to the distractor is unnecessary to perform either the word task or probe task. When the distractor is cued, spatial attention is assumed to be exogenously directed to that location, yet it should disengage from the distractor and shift to the target look-alike as part of performing the word task. Because the cue predicts the location of the probe, subjects should then try to shift attention back to the distractor's location. However, it is unlikely that this final shift can be accomplished prior to the onset of the probe display as shifts of spatial attention take approximately 100 ms (Woodman & Luck, 1999, 2003), and the word display is only presented for 150 ms. To summarize, it is assumed that: 1) the spatial cue attracts spatial attention to its location in an obligatory manner, 2) when the target look-alike is cued spatial attention should remain at its location, 3) when the distractor is cued, spatial attention should disengage and shift to the target look-alike's location (and back again if possible).

Turning to the predictions of the three accounts, the spatial attention dependence account predicts that spatial attention should be captured by related distractors. When the target look-alike is cued, spatial attention should be drawn to that word, but also to the location of the distractor when it is related. If the probe occurs at the location of the target look-alike (cue valid), probe responses should be slower or less accurate when the distractor is related because it would draw spatial attention away from the probe's location. If the probe occurs at the location of the distractor (cue invalid), probe responses should be faster or more accurate when the distractor is related, because spatial attention should shift to the related distractor's location. When the distractor is cued, spatial attention should first be directed to its location before shifting to the location of the target look-alike. If the probe occurs at the location of the distractor (cue valid), probe responses should be faster or more accurate when the distractor is related because spatial attention should be faster to shift back to the related distractor's location (after shifting to the target look-alike as part of the word task). If the probe occurs at the location of the target look-alike (cue invalid), no differences are expected when the distractor is related versus unrelated because this account does not predict a difference when spatial attention shifts from a related versus unrelated distractor. Statistically a three-way interaction between probe location, cue validity and related distractor presence is predicted.

The delayed disengagement account predicts that shifting attention away from the distractor should produce a cost when the distractor is related versus unrelated. When the target look-alike is cued, no differences between related and unrelated distractor trials are predicted. If the probe occurs at the location of the target look-alike, no shifts of attention are required, and if the probe occurs at the location of the distractor, shifting of attention to that word's location should be unaffected by whether or not it is related. When the distractor is cued, probe responses should be slower or less accurate when the distractor is related versus unrelated. If the probe occurs at the location of the target look-alike (cue invalid), spatial attention should be slower to disengage from a related versus unrelated distractor. If the probe occurs at the location of the distractor (cue valid), spatial attention still needs to shift to the location of the target look-alike as part of the word task, and probe responses should be slower or less accurate when the distractor is related versus unrelated. Statistically a three-way interaction between probe location, cue validity and related distractor presence is predicted, although the nature of this interaction differs from that predicted by the spatial attention dependence account.

Finally, the spatial attention independence account predicts that the benefit for related stimuli is not due to their attracting spatial attention. Shifting spatial attention to or away from a distractor should not be affected by whether or not the distractor is related. Probe responses may be slower or less accurate overall when a related distractor is present, but subjects should be as fast to respond to the probe regardless of where the related distractor appears in the word display. Statistically a main effect of probe location, cue validity and related distractor presence may be present, but no interaction between probe location and related distractor presence should be found.

Method

Subjects. Forty-eight subjects were run in Experiment 3. All had normal or corrected to normal vision, were native English speakers, and received research credit in an introductory level psychology course for participating. Six subjects had an overall accuracy of less than 70% on the probe task or the word task and were replaced.

Stimuli and Equipment. The stimuli and equipment were similar to those used in Experiment 2a. The only difference was that the exogenous spatial cue, described in Experiment 1b, was added. The cue indicated the location of the probe target on 75% of the trials. The target was equally likely to appear at the cued location and the uncued location, as was the related distractor when it was present.

Procedure. The procedure was identical to that of Experiment 2a, except that the exogenous spatial cue was added. It appeared 100 ms prior to the onset of the word display, approximately 5.5^0 visual angle from the center of the fixation cross, and offset when the word display appeared. Each word in the word display was cued equally often. Subjects were instructed that the probe target would appear at the location of the cue on the majority of trials, and would otherwise appear at the opposite location.

Results and Discussion

Because there were so few observations on invalid trials, it was not possible to perform an item analysis for analyses that included those trials. However, for comparisons that examined only valid trials, an item analysis was performed.

Word task. As in Experiments 2a and 2b only accuracy data were collected for the word task. The means are presented in Figure 14. The data were examined in an omnibus 2 (target presence) x 2 (related distractor presence) x 2 (cued word status: target, distractor) x 2 (cue validity: valid, invalid) ANOVA. For data analysis purposes, on target absent trials the target look-alike was coded as the target for the cued word status variable. The main effect of target presence was significant, $F_1(1, 47) = 31.53$, $MSE = 497.510$, $p < .001$, $\eta_p^2 = .40$, as subjects were more accurate when the target was present (M = 86%) than when it was absent (M = 77%). This effect was qualified by two significant interactions. The first was the Target presence x Related distractor presence interaction, $F_1(1, 47) = 54.28$, $MSE = 91.280$, $p < .001$, $\eta_p^2 = .54$. On target present trials subjects were more accurate when the distractor was related (M = 88%) versus unrelated (M = 84%), while on target absent trials subjects were less accurate when the distractor was related (M = 74%) versus unrelated (M = 80%). The second was the Target presence x Cued word status interaction, $F_1(1, 47) = 7.37$, $MSE = 107.58$, $p < .01$, $\eta_p^2 = .14$. Subjects were more accurate when the target (M = 87%) versus the distractor (M = 85%) was cued, but they were less accurate when the target look-alike (M = 76%) versus the distractor was cued (M = 78%). Finally, the Cued word status x Cue validity interaction was also significant, $F_1(1, 47) = 14.78$, $MSE = 136.22$, $p < .001$, $\eta_p^2 = .24$ (see Figure 15). Performance on the word search task was better for valid trials when the cue appeared at the location of the target (M = 84%) versus the distractor (M = 80%), but on invalid trials performance was better when the cue appeared at the location of the distractor (M = 83%) versus the target (M = 80%).

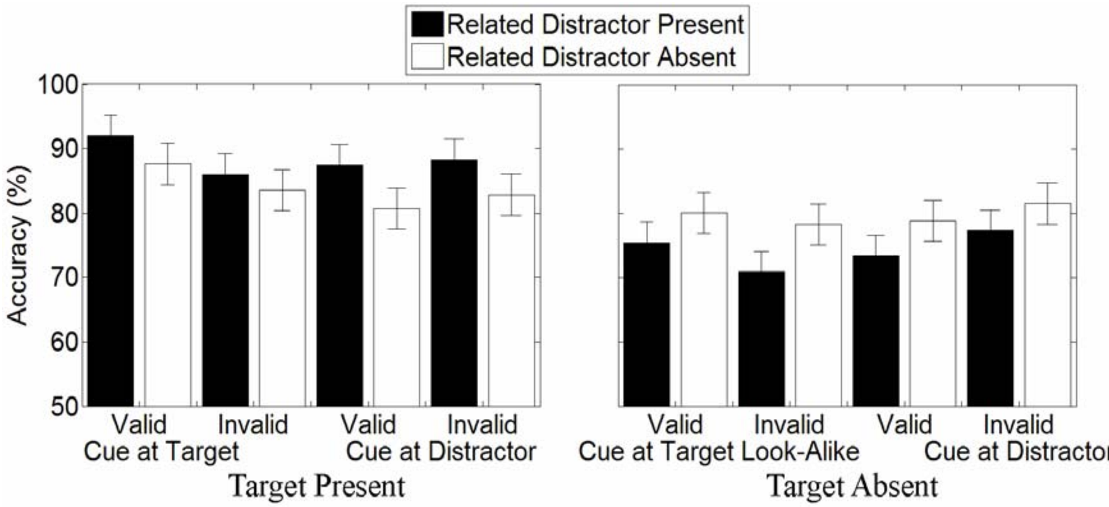

Figure 14. Mean accuracy on the word task in Experiment 3. Error bars are 95% within-subjects confidence intervals for the Target presence x Related distractor presence x Cued word status x Cue validity interaction.

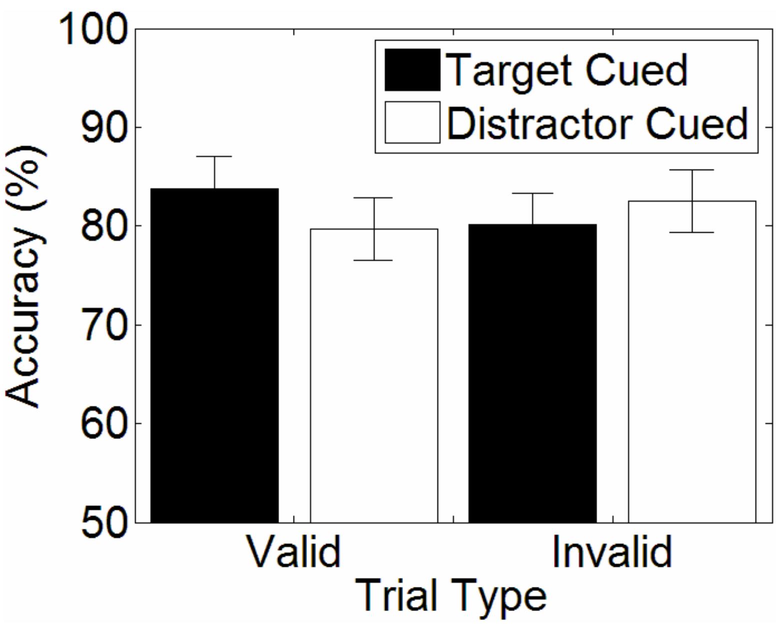

Figure 15. Graphical depiction of the Cued word status x Cue validity interaction. Error bars are 95% within-subjects confidence intervals for the interaction. Note that the 'target cued' variable includes trials where the target and the target look-alike are cued.

The data show that the presence of the related distractor influenced performance on the word task. The interaction between target presence and related distractor presence is similar to that from Experiments 2a and 2b: Subjects were more accurate on target present trials when the distractor was related and they were less accurate on target absent trials when the distractor was related. It is still unclear, though, whether the difference was caused by a bias to respond "present" when the related distractor was present or whether the presence of the related distractor affected the processing of the other word in the display (i.e., the target or target look-alike).

The exogenous spatial cue influenced performance on the word task despite the fact that it did not predict the presence or location of the target. Responses on target present trials were more accurate when the target was cued versus when the distractor was cued. This finding is not surprising given that the cue should have directed spatial attention to the target's location, which would have improved performance. Thus, the spatial cue was effective at capturing spatial attention.

Finally, the Cued word status x Cue validity interaction deserves particular scrutiny (Figure 15). On valid trials performance was better when the cue appeared at the location of the word that looked like the prime (i.e., the target or target look-alike), and on invalid trials performance was better when the cue appeared at the location of the distractor. Stated differently, performance on the word task was better when the probe occurred at the location of the target or target look-alike versus the distractor. Subjects presumably performed the word task by searching for the word that looked like the prime. When the probe appeared at the location of the target or target look-alike and that word was cued, no further shifts of spatial attention were required. When the distractor was cued, subjects should have tried to shift attention back to the location of the distractor because the cue indicated that the probe was likely to occur there. The results suggest, though, that there was not enough time for spatial attention to shift back to the distractor's location, and that spatial attention remained at the target or target look-alike. When the probe appeared at the location of the distractor, spatial attention needed to shift back to that word's location upon completion of the word task, regardless of whether the distractor or the target or target look-alike was cued. This extra shift of attention impaired performance, albeit slightly, on the word task. Because there appears to be a tendency for subjects to attend to the target or target look-alike word, performance on the probe task should be better when the probe occurs at that word's location.

Probe task. The same trimming procedures as in Experiment 2 were employed on the RT data, which lead to the removal of approximately 1.5% of the trials on average per subject. Also, approximately 8% of words in the item analyses were removed due to missing data in the valid conditions. The accuracy and RT data were analyzed separately for target present and target absent trials.

The target present data were examined first via a 2 (probe location: target, distractor) x 2 (cue validity) x 2 (related distractor presence) ANOVA. The accuracy data for target present trials are presented in Figure 16a. The only significant differences were a main effect of probe location, $F_1(1, 47) = 15.09$, $MSE = 178.518$, $p < .001$, $\eta_p^2 = .24$, as responses were more accurate when the probe occurred at the location of the target (M = 97%) versus the distractor (M = 92%), and a main effect of validity, $F_1(1, 47) = 7.74$, $MSE = 154.211$, $p < .01$, $\eta_p^2 = .14$, as responses were more accurate on valid (M = 96%) versus invalid (M = 92%) trials.

The RT data largely correspond with the accuracy data (see Figure 16b). The main effect of probe location was significant, $F_1(1, 47) = 149.56$, $MSE = 23201.789$, $p < .001$, $\eta_p^2 = .76$, as responses were faster when the probe occurred at the location of the target (1047

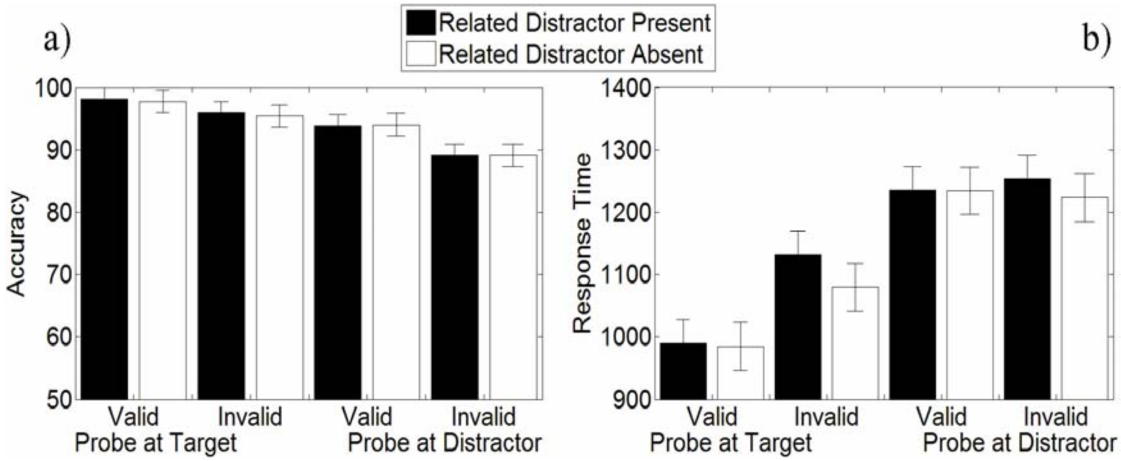

Figure 16. Mean accuracy (panel a) and RT (panel b) on the probe task in Experiment 3 for target present trials. Error bars are 95% within-subjects confidence intervals for the Probe location x Cue validity x Related distractor presence interaction.

ms) versus the distractor (1237 ms). The main effect of cue validity was significant, $F_1(1, 47) = 19.84$, $MSE = 17877.964$, $p < .001$, $\eta_p^2 = .30$, as responses were faster on valid (M = 1111 ms) versus invalid (M = 1172 ms) trials. Finally, the Probe location x Cue validity interaction was significant, $F_1(1, 47) = 17.19$, $MSE = 21055.337$, $p < .001$, $\eta_p^2 = .27$. Responses to probes at the location of the target were faster following valid (M = 988 ms) than invalid cued (M = 1106 ms), but when the probe occurred at the location of the distractor subjects were not faster when the cue was valid (M = 1235 ms) versus invalid (M = 1238 ms).

The target present data indicate that subjects were faster and more accurate to respond to probes that occurred at the location of the target versus the distractor, replicating the results from Experiment 2a and 2b. This finding differs from Moores et al. (2003) who found no benefit in responses to probes appearing at the location of the target. Additionally, valid cues produced faster responses, but only when the probe appeared at the location of the target. These data suggested that subjects shifted attention to the target to perform that task. When the distractor was cued, subjects should have shifted attention back to the distractor word, because the cue predicted the probe's location. However, there may not have been time to shift attention back to the distractor. Thus, when the probe appeared at the location of the distractor, spatial attention was still likely allocated to the target regardless of whether the cue was valid. A benefit for valid versus invalid cues when the probe occurred at the target's location indicates that shifting spatial attention from the distractor to the target (i.e., on invalid trials) is more disruptive than when the target itself was cued. Finally, there were no effects of related distractor presence; the presence of the related distractor did not have any appreciable effects on probe task performance when the target was present. This finding is consistent with Experiment 2a, where the target look-alike was present on target absent trials as it was in this experiment. As discussed previously, the failure to find a difference is expected if target presence overrides the effect of the related distractor.

Turning to the target absent trials, the predictions of the three accounts are presented in Figure 17. A verbal description and explanation for the predictions were presented earlier. A 2 (probe location: target look-alike, distractor) x 2 (cue validity) x 2 (related distractor presence) ANOVA was conducted on the accuracy data. The means are presented in Figure 18a. The only significant effect was a main effect of probe location, $F_1(1, 47) = 11.56$, $MSE = 100.586$, $p = .001$, $\eta_p^2 = .20$, as probe responses were more accurate when the probe appeared at the location of the target look-alike (M = 96%) versus the distractor (M = 92%).

The RT data were more interesting (see Figure 18b). The main effect of probe location was significant, $F_1(1, 47) = 31.13$, $MSE = 31119.180$, $p < .001$, $\eta_p^2 = .40$, as probe responses were faster when the probe appeared at the location of the target look-alike (M = 1159 ms) versus the distractor (M = 1259 ms). The main effect of cue validity was significant, $F_1(1, 47) = 6.38$, $MSE = 29625.437$, $p = .02$, $\eta_p^2 = .12$, as probe responses were

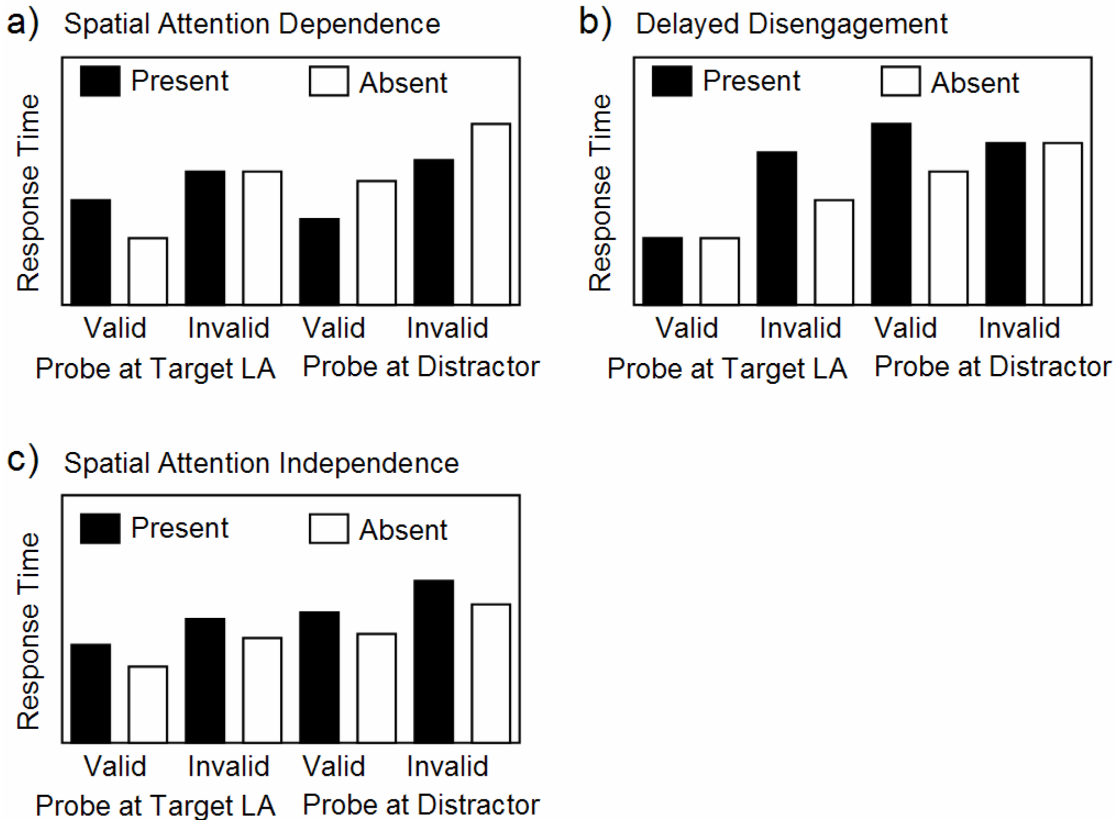

Figure 17. The predictions of (panel a) the spatial attention dependence account, (panel b) the delayed disengagement account, and (panel c) the spatial attention independence account. The graphs represent the Probe location (target look-alike, distractor) x Related distractor presence (present, absent) x Cue validity (valid, invalid) interaction.

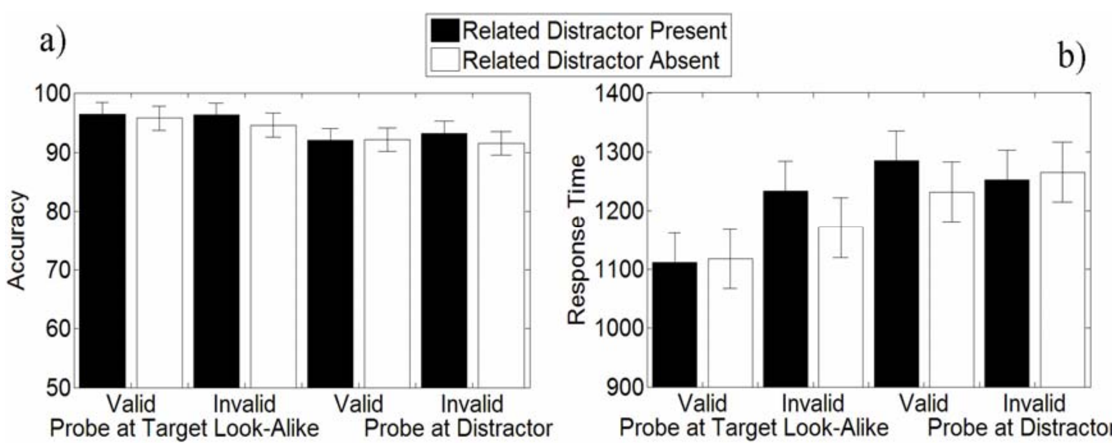

Figure 18. Mean accuracy (panel a) and RT (panel b) on the probe task in Experiment 3 for target absent trials. Error bars are 95% within-subjects confidence intervals for the Probe location x Cue validity x Related distractor presence interaction.

faster following valid cues (M = 1187 ms) versus invalid cues (M = 1231 ms). The main effect of related distractor presence was also significant, $F_1(1, 47) = 6.81$, $MSE = 8236.023$, $p = .02$, $\eta_p^2 = .13$, as probe responses were slower when the related distractor was present (M = 1221 ms) versus absent (M = 1197 ms). The Probe location x Cue validity interaction was significant, $F_1(1, 47) = 10.83$, $MSE = 16919.871$, $p < .01$, $\eta_p^2 = .19$, and showed that responses to probes at the target look-alike location were faster after valid (M = 1114 ms) than invalid trials (M = 1203 ms), but when the probe occurred at the location of the distractor, subjects were not faster when the cue was valid (M = 1259 ms) versus invalid (M = 1259 ms).

Although the Probe location x Cue validity x Related distractor presence interaction was only marginally significant, $F_1(1, 47) = 3.53$, $MSE = 31182.822$, $p = .07$, $\eta_p^2 = .07$, follow up tests were conducted because both the spatial attention dependence and the delayed disengagement accounts predicted a 3-way interaction. Specifically, four within subject t-tests were conducted to determine which of the differences between related and unrelated distractors were significant. On valid trials, when the probe occurred at the location of the target look-alike, there was no difference for subjects, $t_1(47) = 0.34$, $SE = 17.91$, $p = .72$, or items, $t_2(239) = 0.51$, $SE = 23.84$, $p = .61$, but when the probe occurred at the location of the distractor, there was a non-significant trend for RTs to be faster when the distractor was related versus unrelated for subjects, $t_1(47) = 1.63$, $SE = 38.39$, $p = .11$, $\eta_p^2 = .05$, but not for items, $t_2(239) = 1.04$, $SE = 28.40$, $p = .30$. On invalid trials, when the probe occurred at the location of the target look-alike responses were slower when the (cued) distractor was related versus unrelated, $t_1(47) = 2.48$, $SE = 21.52$, $p = .02$, $\eta_p^2 = .12$, but when the probe occurred at the location of the distractor (and the target look-alike was cued) there was no difference,

$t_1(47) = 0.42$, $SE = 30.95$, $p = .68$. These results closely match the predictions of the delayed disengagement account, and do not match those of the spatial attention dependence or spatial attention independence accounts.

The RT data for target absent trials show that the two primary manipulations in Experiment 3 were effective. Responses were more accurate on valid versus invalid trials, although this was only true when the probe occurred at the target look-alike location. The Probe location x Cue validity interaction was similar to that found in the target present data and suggests that subjects may have not had time to shift spatial attention back to the distractor location on valid trials when the distractor was cued. As in Experiment 2a and 2b, probe responses were slower overall when the related distractor was present, indicating that the presence of the related distractor affected performance on the probe task. Probe responses were also faster and more accurate when the probe occurred at the location of the target look-alike, replicating the results of Experiment 2a. Subjects likely treated these words as potential targets by searching for words that were visually similar to the prime. Along with the pattern of data found in the word task, these data suggest that the target look-alike attracts spatial attention during the word task.

Finally, the three-way interaction between probe location, cue validity and related distractor presence was marginally significant. A comparison between Figures 17 and 18b clearly shows that the predictions of the delayed disengagement account were most consistent with the data, and the statistical analyses support this conclusion. Experiment 3 thus provides support for the delayed disengagement account. There is some concern about the fact that the difference in RT to probes occurring at related versus unrelated distractors on valid trials showed a possible trend in the subject analysis but not the item analysis. This discrepancy may be due to losing a relatively large number of items in the item analysis due to missing data compared to Experiment 2, or it may in fact indicate that the difference in the subject analysis is being driven by only a small number of items. However, because the full item analysis could not be conducted due to the missing values in the invalid conditions, and the item analyses generally replicated the subject analyses in Experiment 2a and 2b, it seems reasonably safe to conclude that the subject analysis in Experiment 3 offers a satisfactory understanding of the data, in favor of the delayed disengagement account.

CHAPTER 5. SUMMARY AND DISCUSSION OF EXPERIMENTS 1, 2 AND 3

The purpose of the preceding experiments was to investigate the relationship between spatial and semantic attention. Numerous studies in the literature, reviewed in Chapter 1, have revealed a benefit for the processing of stimuli that are related to a prime or context. Related stimuli are identified more accurately (Palmer, 1975), are more likely to be reported (Dark et al., 1996; Masciocchi & Dark, in revision), and attract fixations (Belke et al., 2008; Meyer et al., 2007; Moores et al., 2003). This benefit for related stimuli is quite consistent and has been found across a range of paradigms.

An unanswered question, though, is what process is responsible for the benefit found for semantically related stimuli? Some of the earliest studies to show a benefit for related stimuli used a semantic priming paradigm, in which a target stimulus is identified or responded to faster when it was related to a prime (e.g., Meyer, Schvaneveldt & Ruddy, 1975). A common explanation was that this benefit was due to spreading activation (Posner & Snyder, 1975) or expectancy (Becker, 1976; Becker & Killion, 1977). More recent studies have shown that spatial attention may also play a role in the benefit for related stimuli. For example, eye fixations, which are believed to precede the allocation of spatial attention (Hoffman & Subramaniam, 1995; Rizzolatti et al., 1987), are more often directed to related than unrelated stimuli. While these studies do not rule out the involvement of processes such as spreading activation, they do suggest that spatial attention is involved.

Three broad accounts for the relationship between spatial attention and semantic attention were identified. The spatial attention dependence account states that the benefit found for related stimuli in the literature is due to their attracting spatial attention. It predicts that spatial attention should be drawn to related versus unrelated stimuli in displays. The delayed disengagement account states that spatial attention is slower to disengage from related stimuli. It predicts that spatial attention should remain longer at the location of related versus unrelated stimuli, and that the benefit for related stimuli is due to a non-spatial process. The spatial attention independence account states that the benefit found for related stimuli is due to a separate process than spatial attention. It predicts that spatial attention should be affected by the presence, but not the location, of a related stimulus, and that the benefit for related stimuli is also due to a non-spatial process.

Although the phenomenon of semantic attention appears to be of interest to many researchers, many attempts to relate it to spatial attention have been unsuccessful or flawed. For example, eye tracking studies have often reported that related stimuli are fixated for a longer period of time than unrelated stimuli, but this finding does not necessarily imply that related stimuli attract eye fixations, and hence spatial attention (Belke et al., 2008; Meyer et al., 2007; Moores et al., 2003). An alternative explanation, discussed earlier, is that spatial attention is slower to disengage once related stimuli are fixated, which would be consistent with the delayed disengagement account. Conversely, subjects may simply elect to fixate those stimuli when doing so would not interfere with the task.

One study in particular that sought to investigate the relationship between semantic and spatial attention was Moores et al. (2003). They had subjects search for a picture of a target object in a search display, and on some trials a related object was presented in the search display. Subjects also performed a probe detection task, in which they had to respond to whether a black dot occurred on the left or right side of the display. Moores et al. reasoned that if related stimuli do draw spatial attention, subjects should be faster to respond to the probe when it appeared spatially close to the related stimulus. No differences in probe performance were found as a function of the location of the related stimulus, although probe responses were slowed overall when a related stimulus was present. However, subjects were also not faster to respond to probes that appeared near target stimuli. This null result seems very surprising given that spatial attention should be directed to target stimuli in the search display, and probe responses have been shown to be affected by spatial attention. A potential methodological problem in this study is that the simple probe detection task may not require focused spatial attention to perform. This explanation would account for why no benefit was found for probes appearing near the location of the target and could account for why related stimuli did not appear to attract spatial attention.

A modification of two common paradigms, the visual search paradigm and the probe detection paradigm, was used to test the relationship between spatial and semantic attention in the current set of studies. In Experiments 2 and 3, subjects searched for a target word in a word display, and then determined whether a probe target, which appeared at the location of one of the words, had a gap on its left or right side. This procedure has two clear benefits over previous ones in the literature. First, unlike eye tracking studies, it uses a more direct measure of spatial attention: RT of the probe discrimination. While eye fixations are a useful measure of where spatial attention is allocated, spatial attention can be dissociated from fixations (Posner, 1980). Thus, eye tracking studies are unable to measure any covert shifts of spatial attention that may occur, while the current procedure can pick up on such shifts. Second, a more appropriate probe task was used than the one by Moores et al. (2003). As discussed previously there is good reason to believe that the simple detection of a black dot probe does not require the focusing of spatial attention. Woodman and Luck (1999; 2003) showed that determining whether a Landolt-C like square has a gap on its left or right side does require focusing spatial attention on the location of the stimulus. Thus, differences in RT on the probe discrimination task should be a more sensitive measure of where spatial attention is directed in the word display with faster RTs expected when the probe appears at the location of a target versus a distractor.

Experiments 1a and 1b were conducted to insure that the word task and the probe task were effective at influencing semantic attention and measuring the allocation of spatial attention, respectively. In Experiment 1a subjects just performed the word task, which involved determining whether a prime word occurred in the word display. The results showed that responses were more accurate on target present trials when the related distractor was present and were slower on target absent trials when the related distractor was present. Thus, performance on the word task did appear to be influenced by whether or not a related distractor was present. However, accuracy was overall quite low, particularly on target absent trials. Therefore, for Experiments 2 and 3 the word task was modified to make it easier. In Experiment 1b subjects performed the probe task without the word task. An exogenous spatial cue, a black circle, signaled the location of the probe target on 75% of the trials. Previous studies have showed that spatial attention is involuntarily drawn to the location of exogenous cues. Thus, to the extent that the probe task is a good measure of where spatial attention is allocated, subjects should be faster or more accurate or both when the probe occurred at the cued location versus a non-cued location. The results confirmed that this was the case. Thus, Experiment 1a showed that a modified word task should be capable of influencing semantic attention, and Experiment 1b confirmed that the probe discrimination task was influenced by the allocation of spatial attention.

The word task and probe task were combined in Experiment 2a. Subjects saw the word display followed by the probe display, and then made a speeded response to the probe followed by an unspeeded response to the word task. The predictions of the three accounts were tested. Several results were important. First, accuracy on the probe task was influenced by whether the related distractor was present. Responses were more accurate on target present trials and less accurate on target absent trials when the related distractor was present, suggesting that the semantic relationship between the prime and distractor was influencing performance. The modified word task thus appeared to be effective. Second, probe responses were faster and more accurate when the probe appeared at the location of the target. This result differed from Moores et al. (2003), but it was consistent with the hypothesis that the probe discrimination task was a better measure of where spatial attention was allocated than their probe detection task. Third, probe responses were also faster and more accurate when the probe appeared at the location of a target look-alike on target absent trials, suggesting that words that look like the target attract spatial attention. This finding provided the impetus for Experiment 2b. Finally, probe responses were not affected by the location of the related distractor. Similar to Moores et al., responses were slower overall when the related distractor was present, but only on target absent trials. Note that this finding does not mean that the related distractor affected spatial attention. Instead the presence of the related distractor may have simply slowed responses on the probe task by slowing subjects' decision on the word task. The results of Experiment 2a were thus consistent with both the delayed disengagement and spatial attention independence accounts. Subjects also appeared to be faster to disengage spatial attention from the target look-alike versus the target in the word display, which would be consistent with the delayed disengagement account because the target look-alike was not a related word.

In Experiment 2a responses to probes occurring at target look-alikes were faster and more accurate than to probes at distractors. The spatial attention dependence and delayed disengagement accounts predict that the effects of related distractors should be strongest when the target is absent, because the presence of the target in the word display may override any influence of the related distractor. Similarly, on target absent trials in Experiment 2a the target look-alike may have also overridden any effects of the related distractor due to its visual similarity to the target. Specifically, when instructions influence strategic direction of spatial attention, as expected for completing the word task, the effect of the related word on a subsequent probe may be overridden. Thus, in Experiment 2b the target look-alike was removed.

Experiment 2b was a replication of Experiment 2a except that stimuli coded as target look-alikes appeared with different primes, so that on target absent trials a visually *dissimilar* target look-alike appeared with either a related or unrelated distractor. If related distractors attract spatial attention, as the spatial attention dependence account predicts, then these conditions should be the most conducive for finding evidence of spatial attention capture. As in Experiment 2a, responses on the word task when the related distractor was present were more accurate on target present trials and less accurate on target absent trials. Probe responses were also faster and more accurate when the probe appeared at the location of the target on target present trials, and were less accurate when the related distractor was present. Similarly, on target absent trials probe responses were slower when the related distractor was present but were unaffected by whether the probe occurred at the location of the related distractor or the other distractor. In other words, the predictions of the spatial attention dependence account were not confirmed. It was not possible to differentiate between the predictions of the delayed disengagement and spatial attention independence accounts, however, because they were identical. A situation in which spatial attention was pre-directed to the location where the related distractor would appear was required to test the predictions of the delayed disengagement account.

Experiment 3 provided such an opportunity. An exogenous spatial cue similar to that used in Experiment 1b was presented prior to the onset of the word display at the location of one of the words in that display. The cue indicated the location of the probe on 75% of the trials and subjects were informed of this fact. The cue was an exogenous cue for the word task (i.e., spatial attention should be involuntarily allocated to the cue's location in the word display) and an endogenous cue for the probe task (i.e., subjects should have tried to use the location of the cue to direct their attention on the probe task). In all other respects Experiment 3 was identical to Experiment 2a. Several results were noteworthy concerning performance on the word task. First, the word task was influenced by the presence of the related distractor in the same manner that it was in previous experiments. Second, the spatial cue did influence performance on the word task. On target present trials responses were more accurate when the cue appeared at the location of the target in the word display than when it appeared at the location of the distractor. This finding shows that attention was exogenously drawn to the location of the probe. Finally, performance was better when the probe appeared at the location of the target or target look-alike. Experiment 2a showed that those words were spatially attended. When the probe appeared at the other location a shift of spatial attention was likely required to identify the probe, which likely caused a reduction in performance on the word task.

Turning to the probe task, probe responses were once again faster and more accurate when the probe appeared at the location of the target or look-alike word. Also, on target absent trials responses were slower when the related distractor was present versus absent. There were two novel findings. First, performance was better on valid versus invalid cue trials when the target or target look-alike was cued, suggesting that subjects were using the spatial cue on the probe task. Second, on target absent trials when the distractor was cued, responses to the probe were slower when the distractor was related versus when it was unrelated. When the distractor is cued, spatial attention is presumably involuntarily drawn to that word's location by the spatial cue. However, spatial attention must disengage as part of the word task so subjects can determine whether or not the other word is the target. The results showed that performance was impaired when the distractor was related versus unrelated. This finding is consistent with the predictions of the delayed disengagement account, which are that performance should suffer when spatial attention shifts away from a related versus unrelated distractor. Thus, based on the results of Experiments 2 and 3, the delayed disengagement account appears to provide the most accurate description of the relationship between spatial and semantic attention.

The delayed disengagement account, originally proposed by Stolz (1996) explains the relationship between spatial and semantic attention by positing that related stimuli become more activated than unrelated stimuli due to their being consistent with a prime or context. The activation for related words reflects a process such as spreading activation and is not based on spatial attention. According to Stolz, the location of the stimulus also becomes activated, and accordingly is more activated when the stimulus is related versus unrelated. This activation in the spatial system affects the disengagement of spatial attention from that word's location, which would produce a cost in responding to a target when the target appears at a different location. The higher level of activation in the location system itself does not produce a cost in disengaging attention; the difficulty arises when spatial attention must shift from that location to a different location. Again, the related stimulus itself does not attract spatial attention, but once spatial attention is direct to its location it is slower to disengage. Unfortunately, Stolz's description of the delayed disengagement account is vague on some points. For instance, it is unclear why spatial attention should be slower to disengage from a more active than a less active stimulus. Also, Stolz did not specify whether location information is part of the representation of a stimulus or whether location is represented in a separate system. These points will need to be clarified in future work.

Given the amount of research and apparent interest in semantic attention, one may be curious as to why more authors do not subscribe to the delayed disengagement account. Stolz (1996) and Stolz and Stevanovski (2004) presented their findings in terms of delayed disengagement, but few others have done so. The likely reason is that too few studies that have examined semantic attention have used a manipulation to direct subjects' spatial attention to related stimuli, which Stolz and Stolz and Stevanovski did by using exogenous spatial cues. For example, several eye tracking studies (Huettig & Altmann, 2005; Huettig & Hartsuiker, 2008; Yee & Sedivy, 2006) simply presented subjects with a display of objects to view. Differences in fixation time between related and unrelated stimuli were often not found until 600 ms after the onset of the display (e.g., Yee & Sedivy, 2006). As mentioned previously, these results can be explained by the delayed disengagement account if it is assumed that the difference is due to subjects fixating related stimuli longer once they attend to that location, and not, as some authors imply, that related stimuli capture attention. This possibility can be tested by spatially cueing a related versus unrelated distractor on each trial and measuring how long subjects' attend to it. The delayed disengagement account would predict that the related stimulus should be fixated longer, while the spatial attention dependence account would predict no difference. Moores et al. (2003), who failed to find that related objects attract spatial attention, also did not use spatial cues. Therefore, according to the delayed disengagement account, no benefit for probes appearing at the location of related stimuli would be expected, just an overall slowing when the related object was present. As discussed later, however, this general slowing may in fact be due to delayed disengagement.

It is also the case that many studies in the literature that explore the influences of related stimuli are beyond the scope of the delayed disengagement account. Only studies in which spatial attention is directly allocated to a related stimulus can produce evidence for delayed disengagement. For example, results from the early priming studies (Meyer & Schvaneveldt, 1971; Meyer et al., 1975) that showed a benefit in processing related versus unrelated primes cannot be interpreted in the delayed disengagement account framework. In describing the delayed disengagement account, Stolz (1996) made it clear that some process produces extra activation for the related word, such as spreading activation. It is this process, rather than the delay in disengaging spatial attention, which is presumably operating in these and similar studies.

Several eye tracking studies have reported that related stimuli do attract initial fixations (e.g., Belke et al., 2008; Meyer et al., 2007; Moores et al., 2003). These findings contrast with those from Huettig and Altmann (2005) and Huettig and Hartsuiker (2008), who did not find a difference between related and unrelated distractors until after the first fixation. Given the discrepancies, it is unclear which finding the delayed disengagement account should be applied to. A number of methodological problems will need to be addressed first. For example, some researchers (e.g., Moores et al.) presented prime related objects more than once, which could have produced expectancy for those stimuli. Also, different dependent measures of eye fixations were used across the different studies.

Three other relevant questions about the literature can be considered within the delayed disengagement framework. The first is how well can the delayed disengagement account explain the results of Dark et al. (1996) and Masciocchi and Dark (in revision), who did present related words and spatial cues in the same display? The most relevant condition for the delayed disengagement account is Experiment 1 of Masciocchi and Dark, when subjects were instructed to report both words. Some subjects were presented with neutral primes and spatial cues, while others were presented with related primes and spatial cues. For these subjects, one word on each trial was related, and half the time the cued word was related. The delayed disengagement account would predict that the uncued word should be reported less often when the cued word is related versus when it was unrelated. Spatial attention should be slower to disengage and shift when the cued word was related, and thus the other word should not be seen as often. This pattern was precisely what was found. When the cued word was unrelated, the uncued word was reported on approximately 40% of the trials, but when the cued word was related, the uncued word was reported on approximately 29% of trials. Thus, the delayed disengagement account does predict the observed pattern of results.

A second question is why in the present set of studies no differences were found for probes appearing at target locations on target present trials when the related versus unrelated distractor was cued. It was stated earlier, rather generally, that the presence of the target may override any effect of the related distractor. How does this explanation fit with the delayed disengagement framework? One possibility is that on target present trials both the related distractor and the target stimuli receive extra activation in the semantic or lexical system, and their locations should be activated as well. Shifting spatial attention from an activated to an inactivated location (from a related to an unrelated distractor) clearly produces cost, but it is possible that shifting spatial attention from an activated to an activated location (from a related distractor to a related target) does not. From a practical perspective this explanation seems plausible. If the purpose of attention is to make relevant information available for awareness, being able to rapidly shift spatial attention from the location of an important (i.e., highly active) stimulus to another important stimulus seems desirable, but shifting spatial attention from an important stimulus to an unimportant stimulus would be less useful. If this conjecture is accurate, then shifting attention away from an activated location is not problematic, per se, as long as the representation of the stimulus in the to-be-attended region is active as well.

The third question is what accounts for the general slowing on related distractor present trials when the target was absent in the literature (e.g., Belke et al., 2008; Meyer et al., 2007; Moores et al., 2003) as well as in Experiments 2a and 2b? While it is possible that there is a general slowing associated with processing a related distractor, no such slowing was found in Experiment 3 on target absent trials when the target look-alike was cued. Interestingly, the delayed disengagement account is able to explain this pattern. It was assumed that in Experiment 2a subjects would direct spatial attention to the target look-alike on a large proportion of trials because that word was visually similar to the prime. However, because there is spatial uncertainty as to the target's or target look-alike's location, on some proportion of trials spatial attention would be directed to the distractor. Then, as part of the word task, subjects should shift spatial attention to the target look-alike. The delayed disengagement account would predict that spatial attention would be slower to disengage when the distractor is related versus unrelated. Thus, the general slowing observed in Experiments 2a could in fact be due to delayed disengagement. Despite the fact that spatial attention was not directed to the distractor via a spatial cue, it should have been spatially attended on some trials leading to slower responses when it was related. Similarly, in Experiment 2b because there was no target look-alike subjects would have to spatially attend to both words in the word display to determine whether the target was present, meaning that the distractor should be spatially attended on an even greater number of trials than it would have been in Experiment 2a. The magnitude of the slowing in related distractor present trials was numerically larger in Experiment 2b than 2a, which would be expected if the slowing was caused by delayed disengagement from the related distractor. This explanation could also account for the general slowing found in Experiment 1a, as well as for the general slowing in the literature. Finally, no slowing was observed on related distractor present trials in Experiment 3, when the target look-alike was cued because there was no reason to attend to the distractor. Thus, the delayed disengagement account can explain the vast majority of data in Experiments 2 and 3, as well as many results in the literature.

Several unanswered questions remain. First, all the studies that have shown direct support for the delayed disengagement account, including the present one, have used words.

Future research should examine whether similar effects are found with pictures of objects. It would be quite simple, in fact, to take Moores et al.'s (2003) design, modify the probe task, and add a spatial cue prior to the onset of the search display. Second, these same studies have used abrupt onset exogenous spatial cues to direct spatial attention. Given that exogenous and endogenous spatial cues appear to operate differently, it would be intriguing to learn whether both types of cues produce delayed disengagement. Given that some evidence for delayed disengagement was found in Experiments 2a and 2b when no spatial cues were present and the distractor should have been naturally attended as part of the word task, it seems likely that endogenous cues would produce delayed disengagement from related stimuli. Finally, the explanation that no delayed disengagement is found on target present trials because shifting spatial attention to an active location is easier than shifting to a less activated location should be tested empirically. Displays that contain two related stimuli versus one related and one unrelated stimulus may be used, and performance can be compared when spatial attention is directed to a related stimulus and must shift to either another related or an unrelated stimulus. If the explanation is accurate, the cost of shifting to the related stimulus should be reduced compared to shifting to the unrelated stimulus.

CHAPTER 6. TEMPORAL PROCESSING OF RELATED STIMULI

Experiment 4

The previous experiments investigated the relationship between spatial and semantic attention using a modified visual search paradigm. The question of interest was whether semantically related stimuli influence spatial attention either by attracting spatial attention to their location or by delaying the disengagement of spatial attention from their location. The next two experiments examined whether semantic attention influences the temporal processing of stimuli through influencing the deployment of spatial attention. According to several models of attention, directing spatial attention to the location of a stimulus speeds the transmission of its feature information through the visual system (e.g., LaBerge & Brown, 1989; Stolz & Stevanovski, 2004). When multiple stimuli are presented in the same display, the features of spatially attended stimuli should be processed faster than the features of unattended stimuli. In other words, spatially attended stimuli should be perceived as occurring prior to concurrently presented unattended stimuli, or ones that occur in close temporal proximity.

Stelmach and Herdman (1991) demonstrated the impact of spatial attention on temporal processing by introducing what has come to be known as the temporal order judgment (TOJ) paradigm. In the TOJ paradigm, two stimuli are presented either simultaneously or in close temporal proximity and subjects judge which of the two stimuli was presented first. Stelmach and Herdman presented two black dots on either side of a fixation cross. An exogenous spatial cue, presented prior to the onset of the TOJ stimuli, drew subjects' spatial attention to one side of the display. Two dots then appeared either simultaneously or at varying SOAs within approximately 100 ms. On some trials the first dot appeared on the cued side of the display, and on the rest of the trials the first dot appeared on the uncued side. The results showed that subjects judged the stimuli appearing on the cued side as appearing sooner than they actually did. When the two dots occurred simultaneously, subjects judged that the cued stimulus appeared first approximately 80% of the time. Subjects were also as likely to judge that a cued stimulus occurring 45 ms after an uncued stimulus had occurred first as they were to correctly judge that the uncued first stimulus had occurred first. The authors argued that the spatially cued stimulus was processed faster than the uncued stimulus, causing subjects to perceive that it occurred sooner than it actually did. Such results suggest that spatially attended stimuli do appear to be processed faster than unattended stimuli.

Similar findings have been demonstrated for stimuli that are associated with a prime. For example, Scharlau (2004) showed that geometrically similar prime shapes were judged as occurring first more often than a simultaneously presented stimulus with a different shape. Stolz (1999) found a similar pattern with words that were semantically related to a prime, even though the meaning of the prime and the words was not task relevant. Subjects were instructed to judge which of two words occurred first; they did not have to semantically process the prime or words in any way. When the two words were presented within 30 ms of each other, words related to a prime were judged as occurring first approximately 8% more often than those same words when no prime was presented. Stolz concluded that the advantage when the words followed a related prime was due to their producing a covert shift of attention, as the pattern she found was similar to that of Stelmach and Herdman (1991) who used spatial cues to produce shifts of spatial attention. This explanation would be consistent with the spatial attention dependence account.

Burnham, Neely, and O'Connor (2006) replicated Stolz's study using repetition primes rather than semantic primes and found that the repeated word was judged as occurring first more often than a simultaneously presented neutral word. However, they questioned Stolz's conclusion that the benefit was due to the identical word's attracting spatial attention. They noted that a similar pattern would be expected if the prime merely reduced the latency for the identical (or related) word to enter awareness without directly influencing spatial attention. This explanation would be consistent with the spatial attention independence account.

Burnham et al. (2006) used a slightly different methodology than Stolz (1999). Stolz had trials on which there either was a prime or no prime and compared the percent of trials that the related (to the prime) word was judged as occurring first on prime trials to the percent of trials that same word was judged as occurring first on no prime trials. In contrast, Burnham et al. presented repetition primes on every trial and examined subjects' accuracy on the TOJ task when the repeated word occurred first versus when a neutral word occurred first. For example, when the two words were separated by a 200 ms SOA and subjects judged which word occurred first, subjects were accurate on 95% of the trials when the repeated word occurred first compared to 58% of the trials when the neutral word occurred first. These results suggest that the repeated word was processed faster than the neutral word, and thus even when the repeated word appeared 200 ms after the neutral word, the TOJ task was quite difficult.

An alternative explanation for these findings is based on strategy, or response bias, rather than speed of stimulus processing: Subjects may have adopted a strategy of responding that the critical stimulus (i.e., the cued, the related, or the repeated stimulus depending on the experiment) occurred first whenever the temporal judgment was ambiguous, namely at short SOAs. However, both Scharlau (2004) and Burnham et al. (2006) found that the benefit for critical stimuli remained even when steps were taken to reduce response biases. One method used in both studies was to instruct half of the subjects to judge which stimulus appeared *second*. If the advantage for critical stimuli was due solely to subjects being biased to respond in favor of the stimulus under conditions of uncertainty, that stimulus should be judged as occurring second as often as it was judged as occurring first, albeit by different subjects. Both Scharlau and Burnham et al. found that the benefit for the critical stimuli was reduced for subjects who judged which stimulus occurred second. For example, Burnham et al. found that with a 200 ms SOA, subjects who judged which word occurred second were correct on 79% of trials when the repeated stimulus was first and 76% of trials when the neutral word occurred first, showing no benefit for repeated words for subjects who judged which word occurred second. Burnham et al. concluded that response bias does appear to be partially responsible for subjects' tendency to judge repeated stimuli as occurring first, as the difference between accuracy when the repeated versus neutral stimulus appeared first was reduced in the judge second group, but according to Burnham et al., subjects also seem to perceive repeated stimuli as occurring sooner than they do. Burnham et al. concluded that judgments on the TOJ task appear to be subject to two influences: perceptual processing and response bias. Because Stolz (1999) did not run a judge second condition, it is not clear whether her effects for related stimuli were due to response bias, faster processing of related stimuli or both.

Experiment 4 was designed to test whether Stolz's (1999) findings could be replicated with the set of stimuli used in the previous experiments, as well as to determine whether an advantage would be found for processing of related words when subjects judged which word occurred second. Based on the findings of Burnhman et al. (2006), a reduction in the magnitude of the benefit for related words in the judge second compared to the judge first condition is expected. According to Burnham et al., this finding would indicate that response bias is partially responsible for the benefit for related words. Specifically, in the judge second condition, response bias would cause subjects to respond that the related word appeared second, whereas in the judge first condition it would cause subjects to respond that the related word appeared first. However, according to the logic of Burnham et al., as long as the *advantage* for judging related words first in the judge first condition is larger than any *disadvantage* for judging related words first in the judge second condition, a benefit in perceptual processing of related words is implicated. Other explanations will be considered later.

Each trial contained a prime, which was sometimes related to one of the two comparison words (see Figure 19). Each word appeared above or below the prime as in Stolz (1999) and Burnham et al. (2006). The second word appeared either after an SOA of 24 ms or 71 ms, or simultaneously with the first word (0 ms SOA). Half of the subjects judged which word appeared first and, following Scharlau (2004) and Burnham et al., half judged which appeared second.

The purpose of Experiment 4 was to test whether a benefit for related words would be found with the stimuli used in preceding experiments, as well as to determine what effect instructing subjects to judge which word occurred second would have on the benefit for related words. A spatial cue will be added in Experiment 5, which will allow a test of the three accounts of the relationship between semantic and spatial attention.

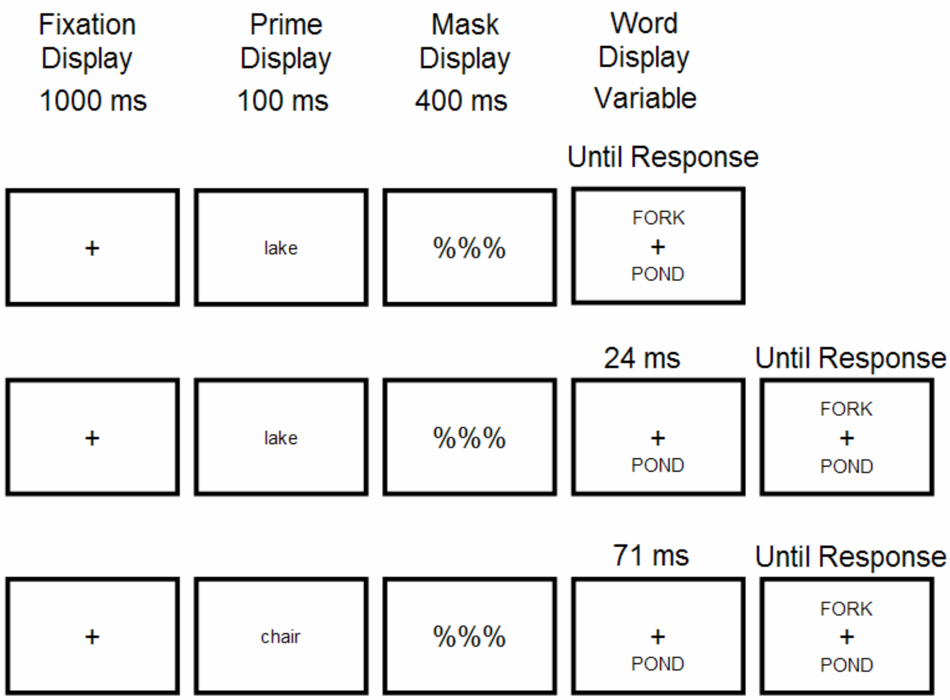

Figure 19. An example of the procedure and several of the trial types in Experiment 4: A) Related prime, 0 ms SOA, B) Related prime, related word first, 24 ms SOA, C) Neutral prime, related word second, 71 ms SOA.

Method

Subjects. Twelve subjects judged which word occurred first and 12 judged which word occurred second, for a total of 24 subjects. All had normal or corrected to normal vision, were native English speakers, and received research credit in an introductory level psychology course for participating. One subject in the judge second group had an overall accuracy lower than 50% and was replaced.

Stimuli and Equipment. The equipment was identical to that used in previous experiments.

The words were the same ones used in Experiment 1a. Sets of 6 prime-associate pairs of similar length were combined to form 40 sets of 12 prime-associate pairs. Each set produced three related prime trials and three neutral prime trials (see Table 4 for an example of how this was accomplished) for a total of 240 trials per subject. For related prime trials,

Table 4. Example of how three related prime and three neutral prime trials were created from a set of 12 prime-associate pairs.

	Words					
Word Type	a	b	c	d	e	f
Prime (1)	coal	fish	fork	floor	grape	grass
Associate (2)	miner	trout	spoon	tile	vine	weed
	g	h	i	j	k	l
Prime (1)	noun	rich	room	sand	pie	sky
Associate (2)	verb	poor	dorm	dune	crust	cloud

Trial Types	Creation of Trial Types		
Subject 1	Prime	Related Word	Unrelated Word
Related	coal (a1)	miner (a2)	trout (b2)
Related	fork (c1)	spoon (c2)	tile (d2)
Related	grape (e1)	vine (e2)	weed (f2)
Neutral	noun (g1)	crust (k2)	cloud (l2)
Neutral	rich (h1)	dorm (i2)	dune (j2)
Neutral	room (i1)	verb (g2)	poor (h2)
Subject 2			
Related	pie (k1)	crust (b2)	cloud (a2)
Related	room (i1)	dorm (d2)	dune (d2)
Related	noun (g1)	verb (f2)	poor (e2)
Neutral	fork (c1)	miner (a2)	trout (b2)
Neutral	fish (b1)	spoon (c2)	tile (d2)
Neutral	coal (a1)	vine (e2)	weed (f2)

the related word was the prime's associate and the unrelated word was an associate of a different prime within the same set. For neutral prime trials, the two unrelated words were the associates of two different primes within the same set. Also for neutral prime trials, one of the two words was coded to be the "related word" for that trial, similar to the procedure used by Stolz (1999). Counterbalancing insured that each prime and associate occurred equally often in all conditions. Primes and associates were never repeated for a given subject.

Procedure. Three example trials are depicted in Figure 19. The procedure was similar to that used by Stolz (1999) and Burnham et al. (2006). Each trial began with a fixation cross for 1,000 ms, followed by the prime word presented in the center of the display for 200 ms. The prime word was then masked by a row of percent signs for 400 ms. The fixation cross then reappeared and remained on the screen for the remainder of the trial. One word appeared simultaneously with the fixation cross either above it or below it. The second word appeared simultaneously, 24 ms (two refresh cycles of the monitor) later, or 71 ms (6 refresh cycles) later in the opposite location. Both words remained on the screen until subjects made a response. The related word was equally likely to appear first or second and to be the top or bottom word. The center of the words was approximately 1.5^0 from the center of the fixation cross. The letters were the same size used in previous experiments, approximately 1.0^0.

Half of the subjects were instructed to judge which of the two words, the top or bottom word, occurred first, and the other half were instructed to judge which word occurred second. All subjects pressed the 'P' key to indicate the top word occurred first or second, and the 'L' key to indicate that the bottom word occurred first or second. As in Stolz (1999) and Burnham et al. (2006), accuracy was emphasized over RT, and thus only the accuracy data were examined.

Subjects were given no explicit instructions about the possible relationship between the prime and two words. Subjects completed 12 practice trials, with neutral and related primes, followed by six blocks of trials containing 40 trials each. Location of the words in the word display (top/bottom), and assignment of words into trial type (neutral or related prime, related or unrelated word) was counterbalanced across subjects. Words were randomly assigned to each SOA condition.

Results and Discussion

The results are presented in terms of accuracy on the TOJ task. The data from the 0 ms SOA condition were analyzed separately, because there was no correct response. As described previously, two types of primes were used: related and neutral primes. On related prime trials one of the two words was related to the prime. On neutral prime trials both of the words were unrelated to the prime, but for data analysis purposes one word was dummy coded as a related word. Thus, on a given trial the prime could be related or neutral, the related word could appear first or second, and the SOA between the two words could be 0 ms, 24 ms, or 71 ms. Finally, half of the subjects judged which word occurred first, and half judged which word occurred second. Also, to preview the main results of Experiments 4 and 5, no item analysis was conducted in either experiment because there no meaningful effects of prime type were found.

71 ms and 24 ms SOAs. The data for the 71 ms and 24 ms SOA conditions were examined via a 2 (prime type: related, neutral) x 2 (SOA: 71 ms, 24 ms) x 2 (related word position: first, second) x 2 (TOJ group: judge first, judge second) ANOVA. The means are presented in Figure 20. To anticipate the results, there was a difference between related and neutral primes in the judge first group (i.e., the black bars are different than the white bars),

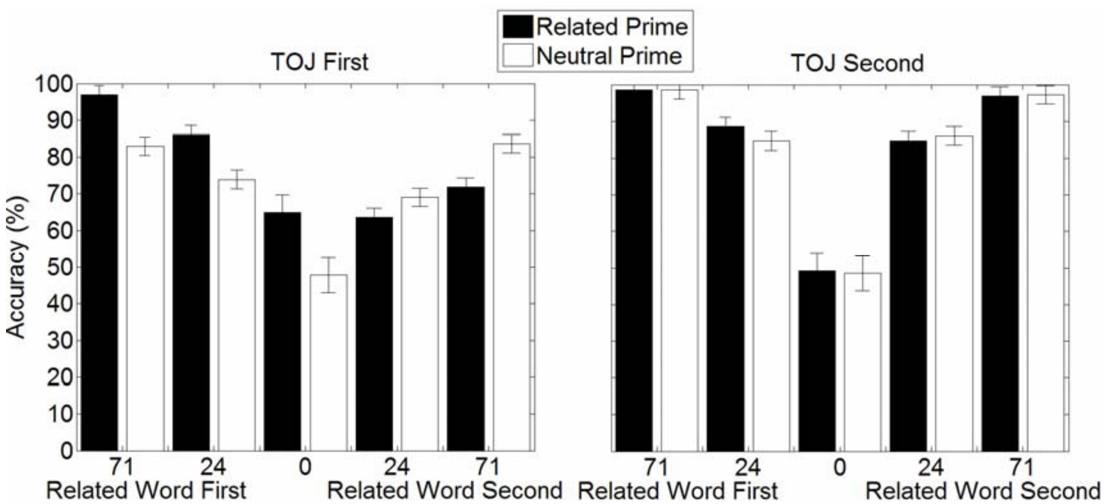

Figure 20. Mean accuracy on the TOJ task for the judge first and judge second groups. For the 75 ms and 17 ms conditions, error bars are 95% within-subjects confidence intervals for the Prime type x SOA x Related word position x TOJ group interaction. For the 0 ms condition, error bars are 95% confidence intervals for the Prime type x TOJ group interaction. Note that in the 0 ms condition the related word occurred at the same time as the other word, and performance reflects the percent of times that the related word was judged as occurring first, not accuracy.

but not in the judge second group. The main effect of SOA was significant, $F_1(1, 22) = 29.75$, $MSE = 203.886$, $p < .001$, $\eta_p^2 = .58$, as subjects were more accurate when the words were separated by a 71 ms SOA (M = 91%) versus a 24 ms SOA (M = 80%). The main effect of TOJ group was also significant, $F_1(1, 22) = 5.24$, $MSE = 1647.644$, $p = .04$, $\eta_p^2 = .19$, as subjects in the judge second group (M = 92%) were more accurate than those in the judge first group (M = 79%). The main effect of related word position was marginally significant, $F_1(1, 22) = 4.01$, $MSE = 599.905$, $p = .06$, $\eta_p^2 = .16$, but was qualified by a significant Related word position x Prime type interaction, $F_1(1, 22) = 4.77$, $MSE = 376.577$, $p = .04$, $\eta_p^2 = .18$, and a marginally significant Related word position x Prime type x SOA x TOJ group four way interaction, $F_1(1, 22) = 3.82$, $MSE = 32.412$, $p = .07$, $\eta_p^2 = .15$. The nature of this interaction was that for the judge second group there was no effect of prime type.

Conversely, the judge first group subjects were more accurate on related versus neutral prime trials when the related word appeared first, and were less accurate on related versus neutral prime trials when the related word appeared second. This difference appeared to be slightly larger at the 71 ms SOA.

0 ms SOA. Because there was no correct response for the 0 ms SOA trials, the data were examined based on the percent of trials that the related word was judged as occurring first. Responses of subjects in the judge second group were reverse coded so that their responses indicated the percent of trials that they reported seeing the related word as occurring first (i.e., the percent of trials in which they responded that the unrelated word occurred second). A 2 (prime type) x 2 (TOJ group) ANOVA was conducted, and the means are presented in Figure 20 (middle two bars of each TOJ group). As can be seen in Figure 20, subjects in the judge first group were more likely to respond that the related word occurred first when it was preceded by a related versus neutral prime. However, subjects in the judge second group were unaffected by prime type. The results of the ANOVA confirm these conclusions. The main effect of prime type, $F_1(1, 22) = 6.54$, $MSE = 143.854$, $p = .02$, $\eta_p^2 = .23$, was significant, and the main effect of TOJ group was marginally significant, $F_1(1, 22) = 3.56$, $MSE = 187.783$, $p = .07$, $\eta_p^2 = .14$. They were qualified by a significant Prime type x TOJ group interaction, $F_1(1, 22) = 5.55$, $MSE = 143.854$, $p = .03$, $\eta_p^2 = .20$. Subjects in the judge first group responded that the related word occurred first more often on related prime (M = 65%) versus neutral prime (M = 48%) trials, $t_1(22) = 2.36$, $SE = 6.63$, $p = .03$, $\eta_p^2 = .25$, but in the judge second group there was no difference in responding that the related word occurred first on related prime (M = 49%) versus neutral prime (M = 49%) trials, $t_1(22) =$

0.20, *SE* = 3.36, *p* = .84 In other words, only subjects in the TOJ first group reported that the related word occurred before the unrelated word.

The main result of the preceding analyses was that subjects in the judge first group are influenced by the related prime. Subjects who judged which word occurred first were more accurate when the related word was first and less accurate when the related word was second, suggesting that they were either biased to respond that the actual related word occurred first or were actually processing the related word faster. In the 0 ms SOA condition, subjects in the judge first condition were more likely to respond that the related word occurred first. Conversely, responses of subjects in the report second group were not influenced by whether the prime was related or neutral.

These results are very similar to Burnham et al.'s (2006) findings. For the 200 ms SOA condition in their study, subjects in the judge first group were more accurate when the repeated prime word occurred first versus second, but subjects in the judge second group showed no difference when the repeated prime word occurred first versus second. Similarly, on related prime trials in the 71 ms SOA condition in the present study, subjects in the judge first group were more accurate when the related word occurred first versus second, but in the judge second group subjects were not more accurate when the related word occurred first versus second.

The results of the judge first group also replicate Stolz's (1999) findings. She found that subjects were more likely to judge that the related word occurred before the unrelated word on related versus no prime trials when the words occurred within 30 ms of each other. In the present study, effects of prime type were found at both the 24 ms and 71 ms SOAs in the judge first group. Specifically, subjects were more accurate on trials with related versus neutral primes when the related word occurred first, and were less accurate on trials with related versus neutral primes when the related word occurred second. In other words, when the related word occurred second and was preceded by a related prime, subjects in the judge first group were more likely to respond that the related word occurred first, as they did in Stolz's study. The same pattern was found in the 0 ms condition: Subjects in the judge first group were more likely to say that the related word occurred first following trials with related versus neutral primes. Thus, the results of Experiment 4 are consistent with those from the literature.

What accounts for the finding that subjects in the judge first condition are influenced by the related prime but not those in the judge second condition? There are at least three explanations. The first explanation is that, as Burhman et al. (2006) argued, TOJs are based on two effects: a response bias to respond in favor of identical (or related) stimuli, and faster perceptual processing of identical (or related) stimuli than neutral stimuli. In the judge first condition these effects go in the same direction; subjects are biased to respond first and the related word is processed faster than the unrelated word making the related word appear to be first. In the judge second condition these effects go in the opposite direction; subjects are biased to respond second but the related word is processed faster, negating any benefit in the speed of processing of the related word. Thus, a benefit for related words is found in the judge first but not the judge first condition. This explanation assumes that there is a real benefit in temporal processing of related stimuli and that the benefit is of similar magnitude to the bias to call the related word second when that is the task.

The second explanation is that subjects in the judge first and judge second groups performed the TOJ task differently. The judge first decision could be described as a more natural task in that it simply requires identifying which word occurred first. A correct decision can be made, for example, by determining which representation of the two stimuli is most activated, as the representations of the first stimulus should be more activate than that of the second. To the extent that related words also are more active, they would be more likely to be experienced as first. The judge second decision is more complicated; in order to know that something is second, you have to know that it was not first. Essentially, it requires identifying which word occurred first and then making the opposite response. It is unlikely that a simple heuristic can be used to make the decision. Subjects may thus be less influenced by the related prime if they are concentrating on performing the assigned task. Thus, the related word may only influence performance on the judge first decision but not the judge second decision. This explanation suggests that there is something fundamentally different about performing the TOJ first and second task, and thus averaging across responses, as Burnham et al. (2006) did, is not appropriate.

The third explanation calls into question the usefulness of the TOJ task to examine effects of relatedness (or repetition) and is not necessarily mutually exclusive with the second explanation. Recall that Burnham et al. (2006) found that even when the neutral word occurred 200 ms SOA before the identical word, subjects were only correct on 58% of the trials. The authors interpreted this result to show that when the repeated word occurs 200 ms after a neutral word the ordering of the two words is essentially indistinguishable. While this may be true, an alternative interpretation is that some subjects in the judge first group misinterpreted the task and instead attempted to identify which of the two words was the repeated word. This strategy would have produced high accuracy when the repeated word occurred first and low accuracy when the repeated word occurred second.

One way to disentangle these explanations would be to examine subjects' performance on a neutral prime trial, when both words are unrelated to the prime. Such a comparison was not available to Burnham et al. (2006) because they only used repeated prime trials, but the comparison can be made with the present results. If this final explanation is accurate, then those subjects who show the biggest difference between related and neutral prime trials should have the worst performance on neutral prime trials, yet be very accurate on related prime trials when the related word is first and very inaccurate when it is second.

To determine whether differences in how people do the task can account for the observed tendency for related words to be judged as occurring sooner than unrelated words in the judge first group, subjects' performance on neutral trials in the two 71 ms conditions was examined. This condition should be the easiest condition in the experiment, and accuracy should be relatively high, however 3 out of the 12 subjects in the judge first group had a mean accuracy of less than 50% (M = 42%) on those trials. The next lowest mean accuracy for the remaining subjects on those trials was 89%. The data from these three subjects are presented in Figure 21a, and the data from the remaining nine subjects in the judge first group are presented in Figure 21b. As can be clearly seen, the difference between related and neutral prime trials observed in Figure 20 appears to be coming exclusively from the three subjects who performed at chance on the neutral prime trials at the 71 ms SOAs. It appears that these subjects were responding based on the location of the related word (i.e., whether the related word was the top or bottom word) rather than which word occurred first (i.e., whether the first word was the top or bottom word). On neutral trials, when neither word was related, they apparently chose a word at random causing their accuracy to be around chance. On related prime trials their responses were either very accurate or inaccurate depending on

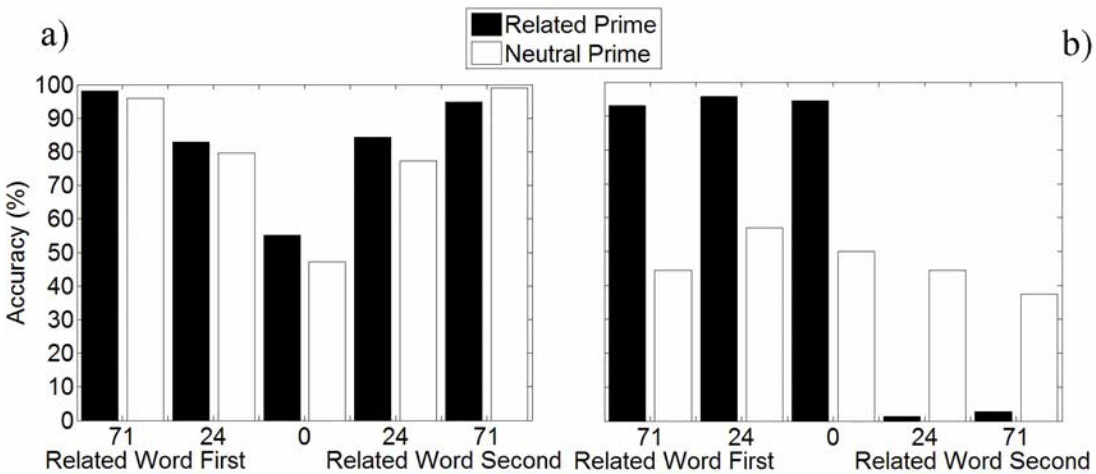

Figure 21. Mean accuracy on the TOJ task for (panel a) the nine subjects in the judge first group who appeared to be doing the task and (panel b) the three subjects in the judge first group who were not. Note that in the 0 ms condition the related word occurred at the same time as the other word.

whether the related word occurred first (left bars) or second (right bars). Conversely, no subjects in the report second group had a mean accuracy of less than 90% on the 71 ms SOA trials following neutral primes, suggesting that all of these subjects were attempting to perform the task as instructed, and additionally, they were not influenced by the presence of a related prime. In Experiment 4, therefore, the advantage for related words following related versus neutral primes appears to be due to a misunderstanding of the instructions (explanation #3), or a response bias (explanation #2), and not due to an advantage for perceptual processing of related words, as Burnham et al. (2006) argued.

CHAPTER 7. TEMPORAL PROCESSING OF RELATED AND CUED STIMULI

Experiment 5

Experiment 4 showed an effect of prime type on the TOJ task, an effect that has been interpreted in the literature as showing that related words are processed faster than unrelated words. Upon closer examination this interpretation is open to an alternative explanation, namely that some subjects respond based on which word was related rather than the order in which the two words occurred. The purpose of Experiment 5, however, was not to determine whether or not semantic relatedness influences speed of processing, but rather to assess which of the three accounts of the relationship between semantic and spatial attention provides the best account of any observed differences. If semantic relatedness does influence capture of spatial attention or leads to a delay in disengaging spatial attention, it could indirectly influence speed of processing. Experiment 5 was identical to Experiment 4 except that a spatial cue, which in previous experiments had been shown to attract spatial attention, was presented prior to the onset of the first of the two comparison words.

The three accounts of the relationship between semantic and spatial attention make different predictions as to the effect that the spatial cue should have on subjects' responses. Given the findings in Experiments 2 and 3, the focus is on determining whether any evidence for delayed disengagement can be found, but for completeness the predictions of all three accounts are presented. The predictions are best described in terms of the interaction between the variables of prime type (related versus neutral primes) and related word cue status (cued versus uncued). The predictions are described for trials when the related word occurs first, and the opposite predictions are made when the related word occurs second. In other words, if a benefit in accuracy for related over unrelated words was predicted when the related word occurs first, then the corresponding prediction is that subjects should be less accurate when the related word occurs second.

The spatial attention dependence account predicts that the advantage in accuracy for related versus neutral primes should be larger when the related word is uncued versus when it is cued. The exogenous spatial cue should direct spatial attention to a particular location. If related stimuli affect temporal processing through attracting spatial attention, then only a small benefit, if any, would be predicted for related cued words following related primes versus neutral primes. Conversely, for uncued words, the related word should attract spatial attention to its location and responses should be more accurate following related than neutral primes. Thus, if any benefit for related primes is found, the spatial attention dependence account predicts an underadditive interaction between prime type and cue status.

At short SOAs the delayed disengagement account predicts that the advantage in accuracy for related versus neutral primes should be larger when the related word is cued versus when it is uncued. If related stimuli affect temporal processing through holding spatial attention at their locations longer, then subjects should be more accurate on trials with related versus neutral primes when the related word is cued. Only a small benefit, if any, is expected when the related word is uncued. Thus, if any benefit for related primes is found, the delayed disengagement account predicts an overadditive interaction between prime type and cue status.

The spatial attention independence account predicts that any advantage in temporal processing for related words is due to a non-spatial process. If related stimuli do affect temporal processing, it is not through spatial attention. Thus, if any benefit for related primes is found, the effects of prime type and spatial cueing should be additive.

Method

Subjects. Forty subjects judged which word occurred first and 40 judged which word occurred second, for a total of 80 subjects. All had normal or corrected to normal vision, were native English speakers, and received research credit in an introductory level psychology course for participating.

Stimuli and Equipment. The stimuli and equipment were identical to those used in Experiment 4, except the spatial cue was added. A pilot study found no difference between related and neutral primes when a cue identical to that from Experiment 1b and Experiment 3 was used, although the advantage for cued versus uncued words was quite large. Therefore, the size of the spatial cue was reduced to approximately 0.5^0 visual angle.

Procedure. The procedure was identical to that used in Experiment 4, except the spatial cue was presented 150 ms before the onset of the first comparison word approximately 1.2^0 above the top word or below the bottom word. It remained on the screen for 100 ms before offset. The related word was spatially cued on half the trials. As in Experiment 4 subjects were provided with no information about the semantic relationship between the prime and TOJ words, although they were told that the location of the black circle (the cue) was not predictive of which word occurred first. Subjects received the same written instructions as subjects in Experiment 4, but research assistants also explained the task to all subjects prior to having them perform the practice trials. The additional instruction was introduced in an attempt to reduce confusion about the task (i.e., what was the response supposed to indicate?).

Results and Discussion

As in Experiment 4 the results are presented in terms of accuracy and the 0 ms SOA data were analyzed separately. The results of Experiment 4 suggested that differences between subjects in following instructions may be responsible for the difference between related and neutral prime trials. To explore whether a similar bias occurred in Experiment 5, subjects' data were first examined based on what should be the easiest neutral prime condition: when the first word was cued and the second word appeared 71 ms later. The assumption was that those subjects who performed poorly on this relatively easy condition were not completing the task as instructed, while those who performed well were at least trying to follow instructions. Three groups of subjects were identified and assigned to groups based on their performance. Subjects who had a mean accuracy of more than 75% were assigned to the *performing task* group (n=30 in judge first group and n=24 in judge second group). These subjects appeared to be doing the assigned task. Subjects who had a mean accuracy between 25% and 75% were assigned to an *ambiguous task* group (n=10 in judge first group and n=10 in judge second group) because at this point, it was unclear on what these subjects were basing their responses. Subjects who had a mean accuracy of less than 25% were assigned to the *Opposite Task* group (n=0 in judge first group and n=6 in judge second group). These subjects, all of whom were in the judge second group, appeared to be responding based on which word occurred first, leading to a very low accuracy in the easiest condition. The means of the performing task and ambiguous task groups are presented in Figures 23 and 24, respectively. The data from the opposite task group were not further examined. Note that assignment to groups was based solely on subjects' performance on neutral prime trials and *not* on performance on related prime trials. Thus, while there was no a priori reason to suspect that either of the groups should be more or less influenced by prime type than the other, the results of Experiment 4 suggest that the biggest differences will likely be found in the ambiguous task group. The predictions of the three accounts are presented graphically in Figure 22.

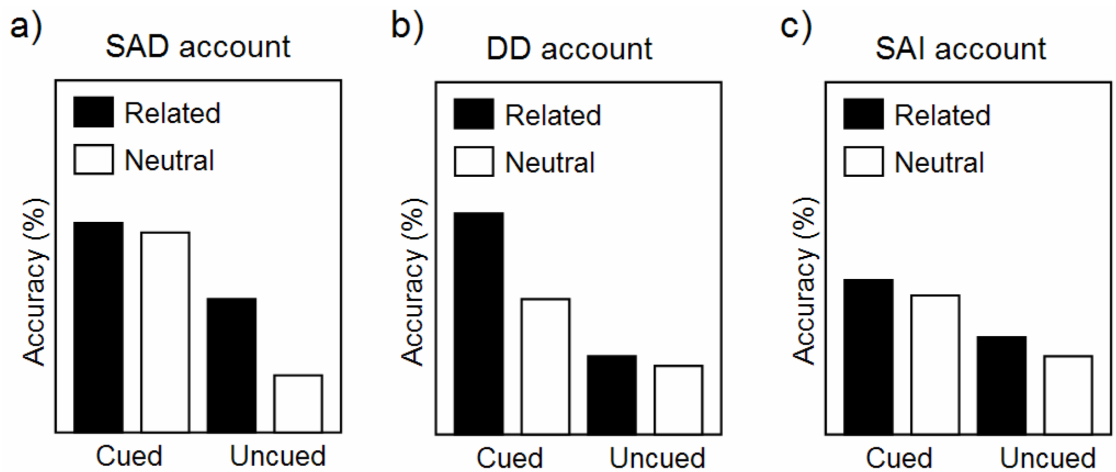

Figure 22. Different predictions for (panel a) the spatial attention dependence account, (panel b) the delayed disengagement account , and (panel c) the spatial attention independence account in Experiment 5. The graphs represent the Prime type (related, neutral) x Related word cue status (cued, uncued) interaction. The data are presented collapsed over SOA, and represent accuracy on the TOJ task when the related word occurs first.

Performing task group. The data for the performing task group were examined via a 2 (prime type) x 2 (SOA) x 2 (related word position) x 2 (TOJ group) x2 (related word cue status: cued, uncued) ANOVA. As can be seen in Figure 23, prime type appeared to have little effect on accuracy, however the spatial cue did influence performance in the same manner for both groups. The main effect of SOA was significant, $F_1(1, 52) = 323.79$, $MSE = 310.541$, $p < .001$, $\eta_p^2 = .86$, and SOA interacted with TOJ group, $F_1(1, 52) = 7.91$, $MSE = 310.541$, $p < .01$, $\eta_p^2 = .13$, as at the long SOA subjects in the judge first group (M = 93%) were more accurate than those in the judge second group (M = 86%), but there was no

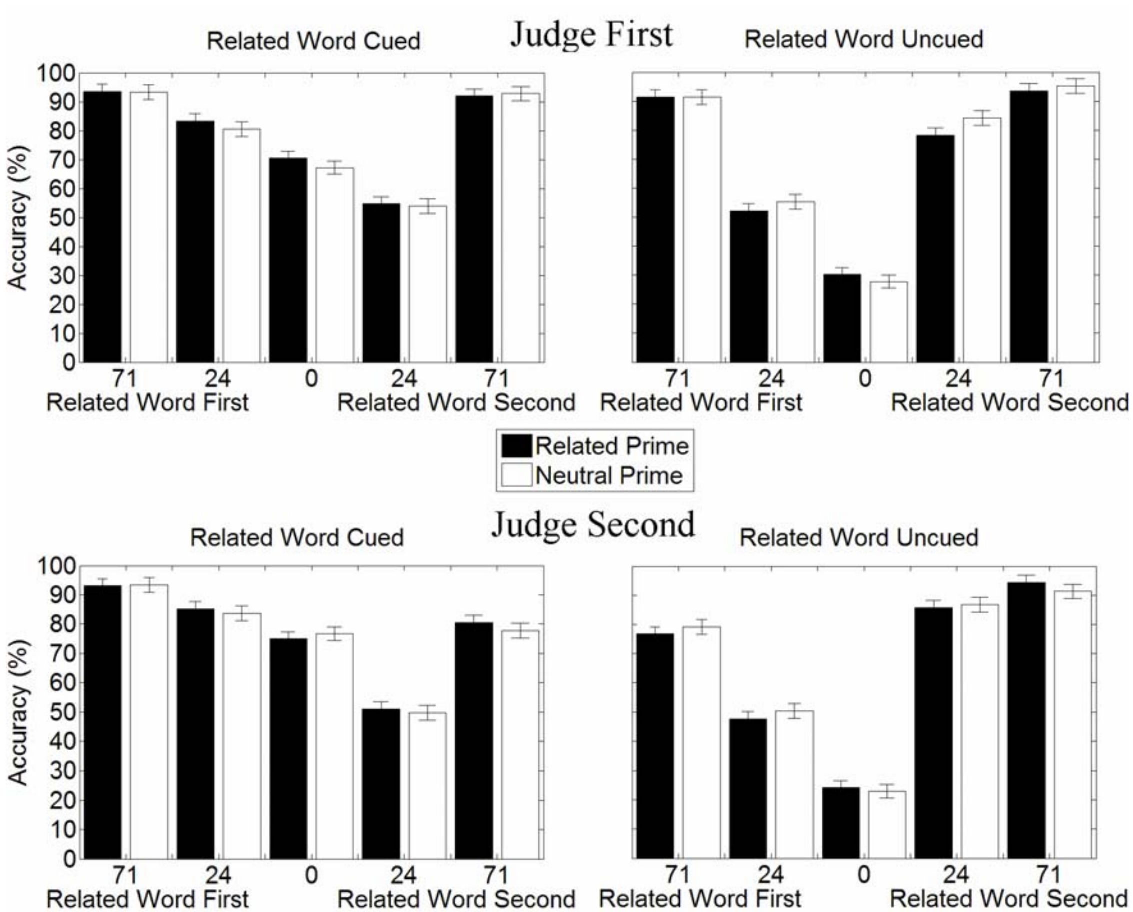

Figure 23. Mean accuracy on the TOJ task for the judge first and judge second groups for subjects in the performing task group. For the 75 ms and 17 ms conditions, error bars are 95% within-subjects confidence intervals for the Prime type x SOA x Related word position x Related word cue status x TOJ group interaction. For the 0 ms condition, error bars are 95% confidence intervals for the Prime type x Related word cue status x TOJ group interaction. Note that in the 0 ms condition the related word occurred at the same time as the other word, and performance reflects the percent of times that the related word was judged as occurring first, not accuracy.

difference between the judge first group (M = 68%) and judge second group (M = 69%) at the short SOA. There was a significant interaction between related word position and related word cue status, $F_1(1, 52) = 40.54$, $MSE = 2095.955$, $p < .001$, $\eta_p^2 = .44$, which was qualified by a significant Related word position x Related word cue status x SOA interaction, $F_1(1, 52) = 51.38$, $MSE = 565.130$, $p < .001$, $\eta_p^2 = .50$. At the 71 ms SOA the spatial cue had only a minor impact on performance, but at the 24 ms SOA subjects were more accurate when the first word was cued versus uncued and less accurate when the second word was cued versus uncued. This finding shows that the spatial cue did influence performance on the TOJ task. There was also a significant interaction between related word cue status and prime type, $F_1(1, 52) = 5.31$, $MSE = 75.535$, $p = .03$, $\eta_p^2 = .09$, which was qualified by a marginally significant Related word cue status x Prime type x SOA interaction, $F_1(1, 52) = 3.26$, $MSE = 67.508$, $p = .08$, $\eta_p^2 = .06$. At the 24 ms SOA, subjects were more accurate on related prime trials when the related word was cued, but on neutral prime trials, and at the 71 ms SOA, there was no interaction with related word cue status. These interactions were the only significant effects of prime type, and the differences between related and unrelated primes were quite small, with a maximum difference of approximately 2-3% in accuracy. However, this pattern is consistent with the predictions of the delayed disengagement account.

Data in the 0 ms SOA condition were examined via a 2 (prime type) x 2 (related word cue status) x 2 (TOJ group) ANOVA. The means are presented in Figure 23 (the middle bars in each graph). The only significant effect was a main effect of related word cued status, $F_1(1, 52) = 84.27$, $MSE = 1342.583$, $p < .001$, $\eta_p^2 = .62$. Cued words were more likely to be judged as occurring first (M = 72%) compared to uncued words (M = 26%), but there was no influence of prime type.

Ambiguous task group. The data for subjects in the ambiguous task group were examined via a 2 (prime type) x 2 (SOA) x 2 (related word position) x 2 (TOJ group) x 2 (related word cue status) ANOVA. Figure 24 shows that the pattern in the judge first and judge second groups was different, particularly for prime type (the difference between the white and black bars). Specifically, the related prime appeared to have the opposite influence

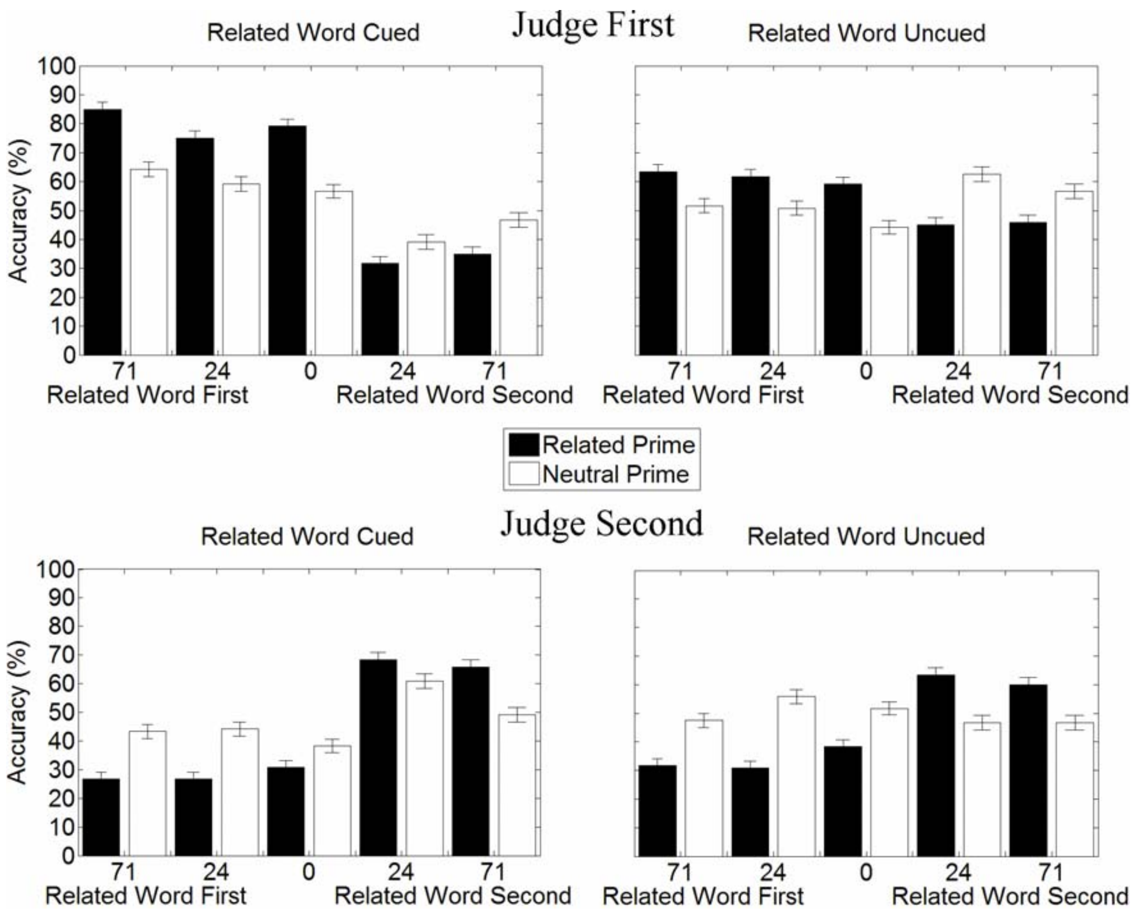

Figure 24. Accuracy on the TOJ task for the judge first and judge second groups for subjects in the ambiguous task group. For the 75 ms and 17 ms conditions, error bars are 95% within-subjects confidence intervals for the Prime type x SOA x Related word position x Related word cue status x TOJ group interaction. For the 0 ms condition, error bars are 95% confidence intervals for the Prime type x Related word cue status x TOJ group interaction. Note that in the 0 ms condition the related word occurred at the same time as the other word, and performance reflects the percent of times that the related word was judged as occurring first, not accuracy.

on subjects in the judge first and judge second groups. The five-way interaction was found to be significant, $F_1(1, 18) = 6.25$, $MSE = 64.164$, $p = .03$, $\eta_p^2 = .26$, and thus the judge first and judge second groups' data were examined separately. For the judge first group, the main effect of related word position was significant, $F_1(1, 9) = 6.80$, $MSE = 2021.420$, $p = .03$, $\eta_p^2 = .43$, but was qualified by a marginally significant Related word position x Prime type interaction, $F_1(1, 9) = 4.18$, $MSE = 1700.238$, $p = .07$, $\eta_p^2 = .32$. When the related word occurred first, subjects were more accurate on related (M = 71%) versus neutral (M = 56%) prime trials, but when the related word occurred second subjects were less accurate on related (M = 39%) versus neutral (M = 51%) prime trials. This pattern suggests that subjects in the judge first group were biased to respond that the related word occurred first. There was also a significant SOA x Related word cue status interaction, $F_1(1, 9) = 5.52$, $MSE = 90.856$, $p = .05$, $\eta_p^2 = .38$. At the 71 ms SOA subjects were more accurate when the related word was cued (M = 58%) versus uncued (M = 54%), but at the 24 ms SOA subjects were less accurate when the related word was cued (M = 51%) versus uncued (M = 55%).

For the judge second group, the main effect of related word position was marginally significant, $F_1(1, 9) = 3.65$, $MSE = 4065.653$, $p = .09$, $\eta_p^2 = .29$, as was the Related word position x Related word cue status interaction, $F_1(1, 9) = 3.45$, $MSE = 499.672$, $p = .10$, $\eta_p^2 = .28$. These were qualified by a significant Prime type x SOA x Related word position x Related word cue status four way interaction, $F_1(1, 9) = 9.00$, $MSE = 30.140$, $p = .02$, $\eta_p^2 = .50$. The interaction appeared to be caused by lower accuracy on related versus neutral prime trials when the related word was first, and higher accuracy on related versus neutral prime trials when the word was second. This difference was larger when the related word was cued versus uncued, but primarily at the 71 ms SOA. Subjects in the judge second group thus appeared to be biased to respond that the related word occurred second, the opposite of subjects in the judge first ambiguous task group.

Data in the 0 ms SOA condition were examined via a 2 (prime type) x 2 (related word cue status) x 2 (TOJ group) ANOVA. The main effect of TOJ group was significant, $F_1(1, 18) = 8.54$, $MSE = 936.539$, $p < .01$, $\eta_p^2 = .32$, but was qualified by a marginally significant interaction between TOJ group and related word cue status, $F_1(1, 18) = 3.62$, $MSE = 981.292$, $p = .08$, $\eta_p^2 = .17$, as well as a significant interaction between TOJ group and prime type, $F_1(1, 18) = 4.72$, $MSE = 901.814$, $p < .05$, $\eta_p^2 = .21$. Subjects in the judge first group were more likely to judge that related words and cued words occurred first, while subjects in the judge second group were more likely to judge that cued words and related words occurred second. The finding that in the 0 ms condition the related prime only influenced performance in the ambiguous task group and not the performing task group suggests that the related prime is not effective when subjects are performing the assigned task, but does influence performance otherwise.

The spatial cue that was re-introduced in Experiment 5 was effective at influencing responses on the TOJ task. In the performing task group, when the first word was cued versus uncued subjects were more accurate than when the second word was cued, particularly at the 24 ms SOA. The corresponding pattern was found in the 0 ms SOA condition for both the performing task group and the ambiguous task group, that is, subjects in the judge first group tended to respond that the cued word occurred first and those in the judge second group tended to respond that the cued word occurred second.

The main question of Experiment 5 was whether any benefit in temporal processing for related words that was observed was due to those words' influencing spatial attention. Given that Experiment 3 provided support for the delayed disengagement account, it was expected that the advantage for related versus unrelated prime trials should be larger when the related word was cued versus when it was uncued, suggesting that spatial attention was slower to disengage from related than unrelated words. There was some evidence that at the 24 ms SOA condition, subjects were more accurate on related versus unrelated prime trials when the related word occurred first and was cued versus when it was uncued. However, the difference was quite small, approximately a 2-3% difference in accuracy, and the interaction was also caused by subjects being less accurate on related versus neutral prime trials when the related word was uncued. Thus, while Experiment 5 may provide some support for the delayed disengagement account, the main result was that differences between related and neutral prime trials were found for the ambiguous task group but not for the performing task group (a comparison of Figures 23 and 24 confirms this statement). In the ambiguous task group, subjects in the judge first group were more accurate on related versus neutral prime trials when the related word occurred first and were less accurate when the related word occurred second. Subjects in the judge second group were more accurate on related versus neutral prime trials when the related word occurred second and were less accurate when the related word occurred first.

What strategy were subjects in the ambiguous task group using to perform the task? While it is obviously difficult to generalize across a group of subjects who by definition are not performing as instructed, one possibility is that they had a bias to respond that the related word was the word they were attempting to identify (i.e., the first word or the second word). Figure 24 shows that subjects in the report second group were less accurate on related than neutral prime trials when the related occurred first, but were more accurate when the related word appeared second, particularly when that word was cued. This pattern suggests that they may have been biased to respond that the related word occurred second. Moreover, performance in the neutral prime condition was approximately 50%, suggesting that may have been selecting between the two neutral words randomly on neutral prime trails. A comparison between the 'Related Word Cued' and 'Relate Word Uncued' panels does show that they were more likely to respond that the cued word occurred second, and they were generally more accurate on long SOA trials. In general the corresponding pattern was seen for the judge first group. Subjects were more accurate when the first word was a related and cued word, and less accurate when the second word was related and cued. Performance on neutral prime trials was around 50%, although performance was clearly affected by the location of the spatial cue, as well as the SOA between words. Taken together, the data suggest that subjects in the ambiguous task group appeared to be biased to respond that the related word, as well as the cued word, was the word that they were judging.

The TOJ paradigm appears not to be sensitive to semantic processing. Those subjects who perform the assigned task do not seem to be influenced by related primes. Those subjects who do not follow instructions are influenced by related primes, but this difference appears to be due to response bias rather than faster temporal processing of related stimuli. Related words thus appear to have minimal or no impact on temporal processing and do not seem to influence spatial attention on this task. Conversely, the advantage for spatially cued stimuli was very robust for the performing task group. The benefit for cued words was in the same direction and of approximately the same magnitude for the judge first and judge second groups, suggesting that the advantage was due to faster temporal processing of attended stimuli and not a response bias. Thus, the TOJ paradigm itself is capable of generating significant differences and is not inherently flawed, but it is not sensitive to semantic processing.

CHAPTER 8. SUMMARY AND CONCLUSIONS

The purpose of this dissertation was to explore whether the resources or processes associated with spatial attention are also involved in semantic attention. Studies in the literature have shown a benefit for processing of semantically related stimuli and cost for processing of semantically unrelated stimuli presented in close spatial and temporal proximity. Three general accounts of this cost and benefit have been put forth. The spatial attention dependence account states that the benefit for related stimuli is because they attract spatial attention, which also produces cost for unrelated stimuli. In this account, similar resources are involved in spatial and semantic attention. The delayed disengagement account states that the benefit for related stimuli is due to a separate, non-spatial process such as spreading activation, while the cost is due to a delay in shifting spatial attention away from related stimuli. The spatial attention independence account states that the benefit for related stimuli and cost for unrelated stimuli is also due to a separate, non-spatial process, and that semantic relatedness does not influences the deployment of spatial attention.

These three accounts were tested across five experiments. Experiment 1 showed that the two primary tasks used in this dissertation, the word task and the probe task, were appropriately sensitive to semantic attention and spatial attention, respectively. Experiment 2 showed that semantically related distractors delay responses to probe targets, producing slower response times when related distractors are present, but do not attract spatial attention. This pattern was replicated in Experiment 2b when the representation of the related stimulus should be the most activated one for those stimuli in the word display. These results provided preliminary evidence against the spatial attention dependence account. An exogenous spatial cue was added in Experiment 3 to provide an appropriate test of the delayed disengagement account. The results showed that when the exogenous spatial cue appeared prior to the onset of the related distractor at the related distractor's location, responses to the probe were delayed. This pattern suggests that spatial attention was delayed in shifting to the location of the other word in the display for completion of the word task. Thus, Experiment 3 provided strong support for the delayed disengagement account. As in Experiment 2 there was no evidence that semantically related distractors attracted spatial attention. Also, the finding that semantic attention did influence spatial attention argues against the spatial attention independence account. Furthermore, the general slowing in Experiments 2a and 2b can also be interpreted in the delayed disengagement framework by assuming that the slowing was caused by spatial attention being slower to disengage from related versus unrelated distractors.

Experiments 4 and 5 tested whether semantic relatedness affects the temporal processing of stimuli through spatial attention. Previous studies using the temporal order judgment task (Stelmach & Herdman, 1991) suggested that directing spatial attention to a stimulus speeds the processing of its features in the visual system. Other researchers have found (Burnham et al., 2006; Stolz, 1999) a similar pattern for related stimuli, namely that related stimuli appear to be processed faster than unrelated stimuli. Experiment 4 replicated previous findings in the literature, but a closer examination of the results indicated that the presumed advantage for processing related stimuli was primarily caused by several subjects who were not performing the assigned task. Those subjects who were performing the assigned task were only moderately influenced by the related word, and only when they judged which word occurred first. In Experiment 5, an exogenous spatial cue was added to test the predictions of the three accounts. As in Experiment 4, however, only a small difference for related versus unrelated words was found for the subjects who were performing the assigned task. And, equally important, those subjects who did poorly on the task were highly influenced by the related word. The results of Experiments 4 and 5 show that the TOJ task is not a useful method for studying semantic attention.

As mentioned, a correct decision on the TOJ task can be made by determining which representation of the two stimuli is most activated or which enters awareness first. Which explanation best accounts for the benefit found for spatially cued stimuli from Experiment 5? That is, was the benefit for spatially cued words due to cued words entering awareness before uncued words, or cued words having a higher activation than uncued words? It seems to depend on what accounts for the lack of benefit for related stimuli for subjects who were performing the assigned task. If related primes do effect the processing of related stimuli, as they did in Experiments 1 to 3, then related stimuli should be more active than unrelated stimuli. Because no difference in TOJ task accuracy was found for these stimuli, the advantage for spatially cued stimuli is likely due to processing speed up; representations of related stimuli are presumably more active than unrelated stimuli, but no advantage is found for those stimuli on the TOJ task because relatedness does not cause processing speed up. Conversely, if related primes do not effect the processing of related stimuli, then the results could due to either temporal speed up or increased activation for cued stimuli. Semantic priming is not observed under some circumstances, for example when subjects perform a letter search on the prime as opposed to reading it (see Maxfield, 1997), suggesting that semantic processing of related stimuli is not always enhanced by related primes. It is possible, then, that semantic processing is also impoverished in the TOJ task, and hence the representations of related words are not more active than those of unrelated words. In fact, subjects do not need to process the semantic meaning of either the prime or the two comparison stimuli, making this explanation relatively likely. If this explanation is accurate, then the benefit for spatially cued words could be due to higher activation in the representation of the cued word or faster temporal processing.

The data from Experiments 1 to 5 showed a benefit for processing spatially attended stimuli, as well as influences of semantic attention. For example, a consistent difference, yet sometimes only a modest one, was found on the word task when the related distractor was present versus absent. Performance was typically better on target present trials and worse on target absent trials, suggesting that the related distractor influenced the interpretation of the other word in the display. In Experiment 3, when the largest effects of spatial attention and semantic attention were found, the data were most consistent with the delayed disengagement account. Just like the spatial attention independence account, the delayed disengagement account hypothesizes that there are two separate processes or resources for spatial and semantic attention. Stolz (1996) argued that the allocation of spatial attention via a spatial cue is unaffected by the presence of semantically related stimuli; the studies conducted in this dissertation provide support for this conclusion. The shifting of spatial attention does appear to be affected by the meaning of stimuli, however. Specifically, spatial attention is slower to shift away from a related versus unrelated stimulus to a new location.

Both the delayed disengagement and spatial attention independence accounts suggest that two separate processes exist for spatial and semantic attention. Spatial attention may operate through a 'spotlight' mechanism, although this metaphor is too restrictive to account for many of the diverse findings in the spatial attention literature. Throughout this dissertation it has been stated that semantic attention may operate through a process such as spreading activation (Collins & Loftus, 1975). What then is meant by attention and is it appropriate to talk about semantic *attention*? If the term attention is reserved for spatial attention, then it is most definitely *not* appropriate to refer to the effects that semantically related stimuli have on processing as semantic attention. However, if attention refers to selective access of information into awareness, which is limited in capacity, then related stimuli do appear to influence attention. For example, in Experiment 3 the related distractor slowed response to the probe task when that word was cued, presumably by delaying the disengagement of spatial attention. The related distractor thus influenced the uptake of information into awareness, despite the fact that the probe was clearly visible on the screen (i.e., the delay was caused by stimulus processing and not sensory processes such as a masking effect). Similarly, performance on the word task was consistently influenced by the related distractor, again suggesting that the related stimulus affected the representation of the other word in the display. Thus, it does seem appropriate to refer to the influence of related stimuli as semantic *attention*.

The preceding five experiments, when interpreted in context of the literature, suggest the following about the relationship between spatial and semantic attention. The benefit that is commonly found for processing related stimuli is not due to their attracting spatial attention, but is due to a spatially invariant set of resources. The allocation of spatial attention via exogenous spatial cues appears to be unaffected by the semantic meaning of stimuli in a display. The only evidence that the processes involved in semantic selection are linked with those involved in spatial selection has to do with disengagement: When spatial attention is allocated to a stimulus, it is slower to disengage from that stimulus' location when that stimulus is related versus unrelated. This pattern cannot be caused by an overall increase in the amount of activation in the system when a related stimulus is present because delayed disengagement was not observed when spatial attention was directed to a different stimulus in the same display via the spatial cue (i.e., the target look-alike) and the related distractor was present in Experiment 3. Both spatial cues and the semantic features of words ultimately influence access into awareness, and to the extent that awareness is limited in capacity, then spatial attention and semantic attention may interact with each other. However, the allocation of semantic and spatial attention resources involves separate processes. For example, spatial attention speeds the temporal processing of attended stimuli's features, but semantic attention does not. Overall, spatial attention and semantic attention appear to involve two separate limited capacity systems.

APPENDIX: LIST OF STIMULI

The following stimuli were presented in Experiments 1 to 5. The nonwords appeared in Experiments 1a and 1b, and the look-alikes appeared in Experiments 2 and 3. A small number of primes and associated words were changed or added in Experiments 2 and 3, and these changes are indicated with an asterisk (*) in the list. Note that because not all primes were used in Experiments 2 and 3, some look-alikes may be unused primes.

		Experimental Trial Items		
Prime	Associate	Look-Alike	Non Word1	Non Word 2
above	below		avobe	aebvo
accept	reject	active	aeccpt	acptce
account	checking		aotccnu	anuctco
accuse	blame		auccse	acsecu
add	sum		adt	adt
after	before		aetfr	arfet
agreement	contract		amegtenee	aregtmnee
air	vent		ari	ari
alcohol	booze		aollcoh	aohllco
alligator	crocodile		aatlrgoig	alglraoti
always	never	almost	aawlys	awysla
angel	halo	angry	aegnl	alneg
anger	rage	ample	aegnr	arneg
ankle	sprain	arena	alkne	aenlk
answer	question		awsner	asernw
apple	core		alppe	aeplp
argue	debate	arose	augre	aerug
arm	leg	art	amr	amr
armor	knight		aomrr	arrom
army	navy	area	aymr	amry
artery	vein		aetrry	atryre
asleep	awake		aelsep	alepse
aunt	uncle	auto	atnu	anut
adventure	explorer		aueretnv	aenrevut
baby	crib	bank	byba	bbay
back	front	both	bkca	back
bag	sack	bay	bga	bga
bake	broil		beka	bkae
ball	bounce	base	blla	blal
ballet	tutu		bllaet	bletal
bank	teller		bkna	bnak

beach	shell	beard	bcaeh	bheca
bear	cub		brae	baer
beautiful	gorgeous		bifeltuut	bateliufu
bee	hive	bet	bea	bea
beef	roast		bfee	beef
beer	keg	beat	bree	bere
beg	plead		bge	bge
bell	chime	bend	blle	blel
belt	buckle		btle	blet
better	worse		btteer	bteret
bike	pedal	bind	beki	bkie
bird	nest	burn	bdri	brid
black	white	blind	bcalk	bklca
blade	razor		bdale	belda
blanket	quilt		bntlaek	bekltan
bleach	clorox	blight	baelch	bechla
blood	plasma		boold	bdloo
board	chalk	bones	braod	bdora
boat	row	bolt	btao	baot
book	text		bkoo	boko
booth	toll		btooh	bhoto
bother	annoy		bhtoer	bteroh
bow	arrow		bwo	bwo
bowl	dish		blwo	bwol
brain	mind	broke	biarn	bnria
branch	twig		bnarch	bachrn
bread	loaf		baerd	bdrae
bride	groom	brass	bdire	berdi
broom	dustpan		boorm	bmroo
brother	sister		btrroeh	behrrot
brush	comb	brook	bsurh	bhrsu
bucket	pail		bkcuet	bcetuk
buffalo	bison		bfoufla	blauoff
bush	shrub	bulk	bhsu	bsuh
buy	sell	bus	byu	byu
cab	taxi	cap	cba	cba
cake	icing		ceka	ckae
camp	tent	cast	cpma	cmap
cancer	tumor	camera	ccnaer	cnerac
candle	wick		cdnale	cnlead
canoe	paddle	cable	conae	ceaon
car	auto		cra	cra
card	credit	cape	cdra	crad
castle	moat		ctsale	csleat
cat	meow	car	cta	cta

catch	throw	candy	cctah	chact
cereal	outmeal		caeerl	cralee
chain	link	check	ciahn	cnhia
chair	table	cheap	ciahr	crhia
cheese	cheddar		ceehse	cesehe
chew	gum		cweh	cehw
church	chapel *priest	change	cruhch	cuchhr
city	town	club	cyti	ctiy
clean	scrub	claim	caeln	cnlae
cliff	ledge	clerk	cfilf	cflfi
climb	ladder	cluck	cmilb	cblmi
clock	alarm	cling	ccolk	cklco
close	open	clear	csole	celso
cloth	fabric		ctolh	chlto
clown	circus	clink	cwoln	cnlwo
clue	hint	clog	ceul	cule
coal	miner	code	clao	caol
coat	jacket	copy	ctao	caot
cold	chill		cdlo	clod
cook	chef	cone	ckoo	coko
coral	reef	combo	carol	cloar
corn	cob	cool	cnro	cron
couch	sofa	comic	ccuoh	chocu
cough	sneeze	comet	cguoh	chogu
cow	moo	con	cwo	cwo
crash	impact		csarh	chrsa
crazy	insane		czary	cyrza
create	invent		caerte	cetera
criminal	suspect		cnialimr	cimalrni
cup	mug		cpu	cpu
cure	remedy		ceru	crue
curse	swear	cubic	csrue	ceusr
curtains	drapes		cirnsatu	crtnsuia
cut	trim		ctu	ctu
danger	hazard		dgnaer	dnerag
dawn	dusk	damp	dnwa	dwan
dead	alive	data	ddae	daed
deaf	mute	deck	dfae	daef
deer	antler	dean	dree	deer
degree	diploma		drgeee	dgeeer
depart	arrive		dapert	dprtea
desert	camel	defeat	desert	dsrtee
devil	demon	delay	divel	dleiv
dinner	supper		dnnier	dnerin
dirt	soil	dice	dtri	drit

dirty	filthy		dtriy	dyitr
ditch	trench		dctih	dhict
dive	scuba		devi	dvie
doctor	nurse	double	dtcoor	dcorot
dog	bark	dot	dgo	dgo
door	knob	does	droo	doro
draw	sketch	drop	dwar	darw
drawer	dresser		dwarer	daerrw
dream	fantasy		daerm	dmrae
dress	gown	drink	dsers	dsrse
drip	leak		dpir	dirp
drugs	addict	drift	dgurs	dsrgu
drunk	sober	dusty	dnurk	dkrnu
dry	wet	die	dyr	dyr
dryer	washer	drown	deyrr	drrey
duck	quack	dump	dkcu	dcuk
dull	shiny	dumb	dllu	dlul
ear	lobe		era	era
early	late	eager	elray	eyalr
earth	planet	eight	etrah	ehatr
east	west	each	etsa	esat
easy	simple	earn	eysa	esay
eat	dine		eta	eta
eggs	omelet	edge	esgg	egsg
empty	full	ended	etpmy	eymtp
enemy	foe	equal	emeny	eynme
energy	kinetic		erengy	eegynr
engine	motor	emerge	eignne	egneni
enter	exit	enjoy	eetnr	ernet
evil	wicked		eliv	eivl
exact	precise		ecaxt	etxca
exam	final		emax	eaxm
exercise	aerobics		eiesecrx	eersexic
eyebrows	tweezers		eoewsrby	eebwsyor
fail	pass	fate	flia	fial
fake	phony		feka	fkae
fall	slip	face	flla	flal
far	near	fan	fra	fra
farm	crops	fear	fmra	fram
fast	swift	fair	ftsa	fsat
fat	thin	fun	fta	fta
father	mother	family	fhtaer	fterah
feel	touch	fell	flee	fele
feet	toes	free	ftee	fete
fence	picket	fever	fcnee	feecn

field	meadow	final	fleid	fdile
fight	brawl	fired	fhgit	ftihg
finger	hand	filter	fgnier	fnerig
finish	done		fsiinh	fnshii
fire	blaze		feri	frie
first	last		fsrit	ftisr
fish	trout	fist	fhsi	fsih
fist	clench		ftsi	fsit
fix	mend	fit	fxi	fxi
flat	tire	fort	ftal	falt
float	raft		faolt	ftlao
floor	tile		foolr	frloo
flower	tulip		fwoler	foerlw
fly	kite		fyl	fyl
fog	mist	fox	fgo	fgo
fold	crease		fdlo	flod
folder	binder		fdloer	flerod
food	meal		fdoo	fodo
football	touchdown		faollbto	fotlloab
forest	woods	formal	ferost	frstoe
forget	forgive		fgroet	fretog
fork	spoon	fond	fkro	frok
fragile	delicate		fgerali	flireag
freedom	liberty		femreod	fodrmee
frog	toad	fowl	fgor	forg
funny	humor	fruit	fnnuy	fyunn
gain	loss	gate	gnia	gian
gang	mob	gaze	ggna	gnag
garbage	trash		gbearga	ggaaerb
garden	hose		gdraen	grenad
gas	fuel	gun	gsa	gsa
gear	shift	gene	grae	gaer
gift	wrap	golf	gtfi	gfit
girl	boy	gave	glri	gril
give	take		gevi	gvie
glove	mitten	glaze	gvole	gelvo
glue	paste	glow	geul	gule
gold	silver	goal	gdlo	glod
good	bad	gone	gdoo	godo
grab	reach		gbar	gabr
grand	canyon		gnard	gdrna
grape	vine	grunt	gpare	gerpa
graph	chart	grown	gparh	ghrpa
grass	weed	grade	gsars	gsrsa
grave	tomb	grant	gvare	gerva

guard	sentry	guide	graud	gdura
guest	visitor		gseut	gtuse
guilt	shame	guess	gliut	gtuli
hammer	nail		hmmaer	hmeram
hang	noose		hgna	hnag
happy	joyous		hppay	hyapp
hat	cap		hta	hta
hay	barn	ham	hya	hya
head	skull		hdae	haed
headache	migraine		hcaheade	hadheeca
hear	listen	heat	hrae	haer
high	low	here	hhgi	hgih
hill	steep		hlli	hlil
hockey	puck		hkcoey	hceyok
hold	grasp		hdlo	hlod
horn	honk	host	hnro	hron
horse	saddle	hotel	hsroe	heosr
hula	hoop	hump	halu	hlua
hunger	famine	humble	hgnuer	hnerug
hurricane	tornado		hcaueinri	hriuecnar
hurry	rush		hrruy	hyurr
ice	cream		iec	iec
indian	tribe		iidnan	idanni
injury	wound	infant	iujnry	ijrynu
innocent	guilty		ienntcon	inontnec
iron	ore		inor	iorn
itch	rash	idle	ihct	icth
jail	prison		jlia	jial
jeans	denim	jelly	jnaes	jsena
jewel	crown	joust	jewel	jleew
jewelry	earring		jeyewrl	jrleywe
joke	riddle		jeko	jkoe
judge	gravel	joint	jgdue	jeugd
jump	leap		jpmu	jmup
jury	trial	jump	jyru	jruy
ketchup	mustard		kcpetuh	kuheptc
key	lock	kid	kye	kye
kidnap	abduct	kettle	kndiap	kdapin
kill	murder		klli	klil
king	queen	kick	kgni	knig
kiss	lips	kids	kssi	ksis
knife	dagger	knelt	kfnie	keifn
knit	yarn		ktin	kint
lake	pond	lady	leka	lkae
land	acre	lead	ldna	lnad

laugh	giggle	large	lguah	lhagu
lawn	mower		lnwa	lwan
lawyer	attorny		lywaer	lweray
learn	teach	legal	lraen	lnera
leave	depart		lvaee	leeva
leaves *leaf	rake	*lamp	lvaees	laesev
legend	myth		legend	lgndee
lemon	lime	lever	lomen	lneom
length	width		lgneth	lntheg
lie	fib		lei	lei
light	bulb	lines	lhgit	ltihg
lightning	thunder		lniigtnht	lgtignnih
lion	roar	limp	lnoi	loin
look	glance		lkoo	loko
lose	win	loan	leso	lsoe
lost	found	list	ltso	lsot
loud	noisy		lduo	luod
love	hate	line	levo	lvoe
maid	butler		mdia	miad
mail	stamp	mile	mlia	mial
mall	plaza	mast	mlla	mlal
many	few	make	myna	mnay
marry	engage	maple	mrray	myarr
meat	raw		mtae	maet
melt	thaw	mesh	mtle	mlet
metal	steel	mercy	matel	mleat
milk	dairy		mkli	mlik
minute	hour		munite	mnteiu
mistake	error		mteiska	mkaiest
mix	blend	map	mxi	mxi
mold	clay	mode	mdlo	mlod
money	cash	model	menoy	myoen
monkey	gorilla		mknoey	mneyok
month	year	moral	mtnoh	mhotn
moon	crater		mnoo	mono
more	less		mero	mroe
mountain	climber		mauintno	muninoat
mouth	tongue	moved	mtuoh	mhotu
movie	film	mouse	mivoe	meoiv
muscle	flex		mcsule	msleuc
music	band	muddy	misuc	mcuis
neat	tidy	neck	ntae	naet
needle	thread	nerves	ndeele	neleed
nephew	niece	nectar	nhpeew	npeweh
nervous	anxious		nvseruo	nuoesrv

neutron	proton		ntneuor	norenut
nice	kind	nuts	neci	ncie
nickel	dime		nkciel	ncelik
noise	sound	noble	nsioe	neosi
nose	snot	noon	neso	nsoe
noun	verb	norm	nnuo	nuon
number	digit		nbmuer	nmerub
ocean	waves	onion	oaecn	oncae
odd	even	oil	odg	odg
old	new	own	odl	odl
operate	surgery		orepeta	otapeer
orange	juice	origin	onarge	oagern
orchestra	symphony		ostraerhe	ocerasrth
over	under		orev	oevr
owe	debt	ore	oew	oew
owl	hoot		olw	olw
oxygen	hydrogen		ogyxen	oyenxg
package	parcel		pkeacga	pgaaeck
pain	hurt	page	pnia	pian
painter	artist		pnraiet	petarin
pancake	syrup		pceanka	pkaaenc
pants	zipper		ptnas	psatn
past	future		ptsa	psat
path	trail	park	phta	ptah
peace	truce		pcaee	peeca
pen	ink	pet	pne	pne
pencil	eraser	permit	pcneil	pnilec
penny	cent	peril	pnney	pyenn
perfume	cologne		pfeermu	pmueerf
persuade	convince		pardeuse	prsdeeau
phone	call	phase	pnohe	pehno
photo	album	pinch	ptoho	pohto
pie	crust *cake	pit	pei	pei
pig	hog	pin	pgi	pgi
pillow	cushion		plliow	plowil
plane	airport		pnale	pelna
plant	seed		pnalt	ptlna
plate	dish	plumb	ptale	pelta
play	game		pyal	paly
plus	minus		psul	puls
poem	sonnet	post	pmeo	peom
poison	venom	pollen	psioon	pionos
poker	cards	pound	pekor	proek
police	officer		piloce	plceoi
pot	pan	pro	pto	pto

pray	kneel	prop	pyar	pary
priest	rabbi		peirst	pistre
prom	tuxedo		pmor	porm
protect	defend		pttroce	pcertot
pull	tug	pure	pllu	plul
punish	scold		pinush	pnshui
purse	handbag		psrue	peusr
push	shove	pump	phsu	psuh
puzzle	jigsaw		pzzule	pzleuz
pyramid	egypt		padyrim	pimydra
quart	pint		qraut	qtura
quiet	silence		qeiut	qtuei
rain	storm	rang	rnia	rian
read	book	rest	rdae	raed
recipe	cookbook		ricepe	rcpeei
rent	lease		rtne	rnet
rich	poor	rise	rhci	rcih
right	left	ready	rhgit	rtihg
river	creek	round	revir	rriev
road	street		rdao	raod
robbery	burglary		rbyobre	rreoybb
rock	stone	roof	rkco	rcok
rod	reel	ray	rdo	rdo
room	dorm	real	rmoo	room
rope	knot	ruin	repo	rpoe
rose	thorn	roll	reso	rsoe
rotten	spoiled		rttoen	rtenot
rough	smooth	royal	rguoh	rhogu
run	jog	red	rnu	rnu
safe	vault	sang	sefa	sfae
salary	wage		sryaal	slryaa
salt	pepper		stla	slat
sand	dune	sale	sdna	snad
save	rescue		seva	svae
scare	fright	scalp	srace	secra
school	campus	second	sohcol	sholco
scream	yell		sercam	sramce
sea	gull		sae	sae
seek	hide	seat	skee	seke
shine	polish	shelf	snihe	sehni
shirt	sleeve *pants	shout	sriht	sthri
shoes	socks	shore	seohs	ssheo
shoot	rifle	shock	sooht	sthoo
shower	bath		swoher	soerhw
sick	ill	sign	skci	scik

sight	vision	skill	shgit	stihg
silk	satin		skli	slik
sink	drain	slim	skni	snik
sit	stand		sti	sti
skip	hop		spik	sikp
sky	cloud		syk	syk
sleep	bed *dream	slide	seelp	splee
smell	odor	smith	sleml	slmle
smile	frown	smart	slime	semli
smoke	cigar	slope	skome	semko
snake	cobra	slave	skane	senka
snow	ski	snap	swon	sonw
soap	suds		spao	saop
soft	hard	soul	stfo	sfot
song	sing		sgno	snog
sorrow	grief		srroow	srowor
soup	broth	sole	spuo	suop
sour	bitter	sock	sruo	suor
speak	talk	spent	saepk	skpae
spider	cobweb	sphinx	sdiper	sierpd
square	circle	squeak	sauqre	sureqa
stain	spot		siatn	sntia
stairs	steps	status	sitars	sarsti
stars	galaxy	stern	srats	sstra
start	begin	stock	sratt	sttra
stereo	radio		sreteo	seeotr
stop	halt		spot	sotp
story	tale	study	sroty	sytro
stove	oven	straw	svote	setvo
stream	brook		sertam	sramte
stress	tension		sertss	srsste
stupid	dumb		sputid	suidtp
sugar	cane		sagur	sruag
suit	vest		stiu	siut
sun	rays		snu	snu
swamp	marsh	sweep	smawp	spwma
sweet	sugar	swung	seewt	stwee
swim	pool	smug	smiw	siwm
tail	wag	tank	tlia	tial
tall	short	task	tlla	tlal
taste	flavor	taxes	ttsae	teats
team	coach		tmae	taem
tear	rip		trae	taer
tears	cry		traes	tsera
teeth	gums	tense	tteeh	thete

temple	shrine		tpmele	tmleep
tennis	racket	temper	tnneis	tnisen
test	quiz	term	ttse	tset
thief	crook	thumb	teihf	tfhei
thirst	quench		trihst	tisthr
throw	toss		torhw	twhor
tick	flea		tkci	tcik
tight	loose	tired	thgit	ttihg
tire	spare		teri	trie
toilet	bathroom		tlioet	tietol
tomato	lettuce		tamoto	tmtooa
tool	wrench		tloo	tolo
tooth	cavity	toast	ttooh	thoto
track	train	trust	tcark	tkrca
travel	luggage		tvarel	taelrv
tree	oak	trip	teer	tere
trouble	mischief		tuerolb	tlbreou
true	false	type	teur	ture
turn	twist		tnru	trun
ugly	pretty		uylg	ulgy
vomit	nausea	voter	vimot	vtoim
vote	ballot		veto	vtoe
waiter	server		wtiaer	wierat
walk	crawl	wait	wkla	wlak
wash	rinse	wave	whsa	wsah
water	flood	wagon	wetar	wraet
weak	strong		wkae	waek
weather	climate		wtreaeh	weherat
wedding	ceremony		wdgedni	wniegdd
weight	scale	weapon	wgieht	wihteg
weird	strange		wried	wderi
wheat	grain	wharf	waeht	wthae
whole	half	wheel	wlohe	wehlo
wild	tame		wdli	wlid
wind	breeze	wide	wdni	wnid
window	shutter		wdniow	wnowid
wine	cork	wish	weni	wnie
winner	loser		wnnier	wnerin
wood	lumber		wdoo	wood
wool	sheep	worn	wloo	wool
work	labor		wkro	wrok
world	globe		wlrod	wdolr
worry	concern		wrroy	wyorr
worst	best		wsrot	wtosr

Practice Trial Items

Prime	Associate	Look-Alike	Non Word1	Non Word 2
outlaw	bandit		tpryoh	olatwu
bottle	money		trohat	blotet
case	weight/knife		csea	ceas
collar	shout/tie		calrol	cloalr
trophy	award		otaowl	thypor
help	ability/hollow		hpel	hlep
trace	handle/truck		tcare	taerc
ship	pad		siph	betlot
crowd	erupt/mob		cdrow	cowrd
throat	neck/throat		toatrh	spih
dark	shadow/cuddle		dkar	drak

FOOTNOTES

[1] I will use the term 'semantically related' to describe prime-stimulus relationships that are either semantical or associative in nature.

[2] It is theoretically possible that spatial attention might be directed to multiple discrete locations in the word display simultaneously, and thus a singular probe appearing at one location would provide an incomplete index of spatial attention allocation in the word display. However, previous studies have suggested that it is very difficult to 'split the beam' of spatial attention. For instance, in Hoffman and Subramaniam (1995) and Deubel and Schneider (1996) subjects could not simultaneously attend to and make a fixation to two discrete locations. Similarly, Posner et al. (1980) presented subjects with two cues, a primary cue which was valid on 65% of trials and a secondary cue which was valid on 25% of trials. An advantage for targets appearing near the secondary cue was only found when the target was also adjacent to the primary cue, suggesting attention could only be directed to one location. However, others have argued that it is possible to simultaneously attend to two noncontiguous regions without attending to the area between them (e.g., Juola, Bouwhuis, Cooper, & Warner, 1991).

[3] Because the exogenous cues used in these experiments were valid on a majority of trials, their overall influence is likely a combination of bottom-up and top-down down factors.

[4] On lexical decision tasks it is common to refer to these words as primes and targets, respectively. However, because I am using a visual search task, I will instead use nomenclature that is more common to those studies by calling these stimuli primes and

associated words. This terminology allows the term “target” to be reserved for the stimuli determining the appropriate response on each trial (the prime target and the probe target).

[5] For three letter primes, only one nonword could be created while keeping the first letter identical to the prime's, and thus that nonword appeared twice in word displays on target absent trials.

[6] I originally planned to use exogenous and endogenous spatial cues in future experiments, but due to logistical limitations only exogenous cues were used. However, to the extent that exogenous and endogenous cues may influence spatial attention in different ways, and thus interact with semantic attention differently, such a comparison is still theoretically interesting.

[7] Due to a programming error each subject saw both the prime and matched target look-alike word for one triplet from each set, albeit on different trials. For example, referring to Table 2, Subject 1 saw 'arm' on a present-related trial and saw 'art' on a (different) absent-related trial. Ideally, this subject should have seen 'ham.' However, it is unlikely that this error affected the results, as no words were ever repeated and the two trials in question were always presented in separate blocks.

REFERENCES

Aukland, M. E., Cave, K. R., & Donnelly, N. (2007). Nontarget objects can influence perceptual processes during object recognition. *Psychonomic Bulletin & Review, 14,* 332-337.

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.

Bacon, W. F., & Egeth, H. E. (1994). Overriding stimulus-driven attentional capture. *Perception & Psychophysics, 55,* 485-496.

Becker, C. A. (1976). Allocation of attention during visual word recognition. *Journal of Experimental Psychology: Human Perception and Performance, 2,* 556-566.

Becker, C. A., & Killion, T. H. (1977). Interaction of visual and cognitive effects in word recognition. *Journal of Experimental Psychology: Human Perception and Performance, 3,* 389-401.

Belke, E., Humphreys, G. W., Watson, D. G., Meyer, A. S., & Telling, A. L. (2008). Top-down effects of semantic knowledge in visual search are modulated by cognitive but not perceptual load. *Perception & Psychophysics, 70,* 1444-1458.

Biederman, I., Mezzanotte, R. J., & Rabinowitz, J. C. (1982). Scene perception: Detecting and judging objects undergoing relational violations. *Cognitive Psychology, 14,* 143-177.

Burnham, R. B., Neely, J. H., & O'Connor, P. A. (2006). Priming effects on temporal order judgments about words: Perceived temporal priority or response bias? *Psychonomic Bulletin & Review, 13,* 429-433.

Cave, K. K., & Bichot, N. P. (1999). Visuospatial attention: Beyond a spotlight model. *Psychonomic Bulletin & Review, 6,* 204-223.

Cave, K. R., & Pashler, H. (1995). Visual selection mediated by location: Selecting successive visual objects. *Perception & Psychophysics*, 57, 421-432.

Clark, H. H. (1973). The language-as-fixed-effect fallacy: A critique of language statistics in psychological research. *Journal of Verbal Learning and Verbal Behavior, 12,* 335-359.

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

Cooper, R. M. (1974). The control of eye fixation by the meaning of spoken language: A new methodology for the real-time investigation of speech perception, memory, and language processing. *Cognitive Psychology*, *6,* 84-107.

Corbetta, M., & Shulman, G. L. (2002). Control of goal-oriented and stimulus-driven attention in the brain. *Nature Reviews Neuroscience, 3,* 201-215.

Cristescu, T. C., & Nobre, A. C. (2008). Differential modulation of word recognition by semantic and spatial orienting of attention. *Journal of Cognitive Neuroscience, 20*, 787-801.

Cristescu, T. C., Devlin, J. T., & Nobre, A. C. (2006). Orienting attention to semantic categories. *Neuroimage, 33,* 1178–1187.

Dahan, D., & Tanenhaus, M. K. (2005). Looking at the rope when looking for the snake: Conceptually mediated eye movements during spoken-word recognition. *Psychonomic Bulletin & Review, 12,* 453-459.

Dark, V. J., Vochatzer, K. G, & VanVoorhis, B. A. (1996). Semantic and spatial components of selective attention. *Journal of Experimental Psychology: Human Perception and Performance, 22*, 63-81.

Davenport, J. L. (2007). Consistency effects between objects in scenes. *Memory & Cognition, 35,* 393-401.

Davenport, J. L., & Potter, M. C. (2004). Scene consistency in object and background perception. *Psychological Science*, 15, 559-564.

Davenport, J. L., & Potter, M. C. (2005).The locus of semantic priming in RSVP target search. *Memory & Cognition, 33,* 241-248.

De Graef, P., Christiaens, D., & D'Ydewall, G. (1990). Perceptual effects of scene context on object identification. *Psychological Research/Psychologische Forschung*, *52,* 317-329.

Desimone, R. & Duncan, J. (1995). Neural mechanisms of selective visual attention. *Annual Review of Neuroscience, 18*, 193-222.

Deubel, H., & Schneider, W. X. (1996). Saccade target selection and object recognition: Evidence for a common attentional mechanism. *Vision Research, 36,* 1827–1837.

Devlin, J. T., Matthews, P. M., & Rushworth, M. F. S. (2003). Semantic processing in the left inferior prefrontal cortex: A combined functional magnetic resonance imaging and transcranial magnetic stimulation study. *Journal of Cognitive Neuroscience, 15,* 71-84.

Duncan, J. (1984). Selective attention and the organization of visual information. *Journal of Experimental Psychology: General*, *114,* 501-517.

Egly, R., Driver, J., & Rafal, R. (1994). Shifting visual attention between objects and locations: Evidence from normal and parietal lesion subjects. *Journal of Experimental Psychology: General, 123,* 161-177.

Eriksen, C. W., & Hoffman, J. E. (1972). Temporal and spatial characteristics of selective encoding from visual displays. *Perception & Psychophysics*, *12,* 201-204.

Fernandez-Duque, D. & Johnson, M. L. (2002). Cause and effect theories of attention: The role of conceptual metaphors. *Review of General Psychology, 6*, 153-165.

Folk, C. L., Remington, R. W., & Johnston, J. C. (1992). Involuntary covert orienting is contingent on attentional control settings. *Journal of Experimental Psychology: Human Perception & Performance*, *18,* 1030-1044.

Gordon, R. D. (2006). Selective attention during scene perception: Evidence from negative priming. *Memory & Cognition, 34*, 1484-1494.

Gronau, N., Neta, M. & Bar, M. (2008). Integrated contextual representations for objects' identities and their locations. *Journal of Cognitive Neuroscience, 20,* 371-388.

Henderson, J. M., Weeks, Jr., P. A., & Hollingworth, A. (1999). The effects of semantic consistency on eye movements during complex scene viewing. *Journal of Experimental Psychology: Human Perception and Performance, 25*, 210-228.

Hoffman, J. E., & Subramaniam, B. (1995). The role of visual attention in saccadic eye movements. *Vision Research, 57,* 787–795.

Hoffman, J. E., & Nelson, B. (1981). Spatial selectivity in visual search. *Perception & Psychophysics*, *30,* 283-290.

Hollingworth, A., & Henderson, J. M. (1998). Does consistent scene context facilitate object perception? *Journal of Experimental Psychology: General, 127,* 398-415.

Huang, L., & Pashler, H. (2007). Working memory and the guidance of visual attention: Consonance-driven orienting. *Psychonomic Bulletin & Review, 14,* 148-153.

Huettig, F., & Altmann, G. T. M. (2005). Word meaning and the control of eye fixation: Semantic competitor effects and the visual world paradigm. *Cognition*, *96,* 23-32.

Huettig, F., & Altmann, G. T. M. (2007). Visual-shape competition during language-mediated attention is based on lexical input and not modulated by contextual appropriateness. *Visual Cognition*, *15,* 985-1018.

Huettig, F., & Hartsuiker, R. J. (2008). When you name the pizza you look at the coin and the bread: Eye movements reveal semantic activation during word production. *Memory & Cognition, 36,* 341-360.

James, W. (1890/1950). *The principles of psychology*. New York: Dover.

Johnston, W. A., & Dark, V. J. (1986). Selective attention. *Annual Review of Psychology*, *37*, 43-75.

Jonides, J. (1981). Voluntary vs. automatic control over the mind's eye's movement. In J. B. Long & A. D. Baddeley (Eds.), *Attention and Performance IX* (pp. 187-203). Hillsdale, NJ: Erlbaum.

Juola, J. F., Bouwhuis, E. E., Cooper, C., & Warner, B. (1991). Control of attention around the fovea. *Journal of Experimental Psychology: Human Perception & Performance*, *17,* 125-141.

Kim, M., & Cave, K. R. (1995). Spatial attention in visual search for features and feature conjunctions. *Psychological Science, 6*, 376-380.

Klein, R., & Hansen, E. (1987). Spotlight failure in covert visual orienting. *Bulletin of the Psychonomic Society, 25,* 447-450.

Koivisto, M. & Revonsuo, A. (2007). How meaning shapes seeing. *Psychological Science, 18*, 845-849.

LaBerge, D. (1983). Spatial extent of attention to letters and words. *Journal of Experimental Psychology: Human Perception & Performance, 9,* 371-379.

LaBerge, D., & Brown, V. (1989). Theory of attentional operations in shape identification. *Psychological Review*, *96,* 101-124.

Lachter, J., Forster, K. I, & Ruthruff, E. (2004). Forty-five years after Broadbent (1958): Still no identification without attention. *Psychological Review, 111,* 880-913.

Loftus, G. R., & Mackworth, N. H. (1978). Cognitive determinants of fixation location during picture viewing. *Journal of Experimental Psychology: Human Perception and Performance, 4*, 565-572.

Loftus, G. R., & Masson, M. E. J. (1994). Using confidence intervals in within-subject designs. *Psychonomic Bulletin & Review, 1,* 476-490.

Mack, A. & Rock, I. (1998). *Inattentional blindness*. Cambridge, MA: MIT Press.

Masciocchi, C. M., & Dark, V. J. (in revision). More than "just" priming: Semantic selection produces cost as well as benefit.

Maxfield, L. (1997). Attention and semantic priming: A review of prime task effects. *Consciousness and Cognition*, *6,* 204–218.

McCann, R. S., Folk, C. L., & Johnston, J. C. (1992). The role of spatial attention in visual word processing. *Journal of Experimental Psychology: Human Perception and Performance, 18,* 1015–1029.

McPeek, R. M., & Maljkovic, V., & Nakayama, K. (1999). Saccades require focal attention and are facilitated by a short-term memory system. *Vision Research, 39*, 1555-1566.

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.

Meyer, D. E., Schvaneveldt, R. W., & Ruddy, M. (1975). Loci of contextual effects on visual word recognition. In P. M. A. Rabbit & S. Dormic (Eds.) *Attention and Performance V* (pp. 98-118). New York: Academic Press.

Meyer, A. S., Belke, E., Telling, A. L., & Humphreys, G. W. (2007). Early activation of object names in visual search. *Psychonomic Bulletin and Review, 14,* 710-716.

Moores, E., Laiti, L., & Chelazzi, L. (2003). Associative knowledge controls deployment of visual selective attention. *Nature Neuroscience, 6,* 182-189.

Müller, H. J., & Rabbitt, P. M. A. (1989). Reflexive and voluntary orienting of visual attention: Time course of activation and resistance. *Journal of Experimental Psychology: Human Perception & Performance*, *15,* 315-330.

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.

Neisser, U. (1976). *Cognition and reality*. San Francisco: Freeman.

Nelson, D. L., McEvoy, C. L., & Schreiber, T. A. (1998). The University of South Florida word association, rhyme, and word fragment norms. *University of South Florida,* http://w3.usf.edu/FreeAssociation, August 2009.

Nobre, A. C., Allison, T., & McCarthy, G. (1994). Word recognition in the human inferior temporal lobe. *Nature, 372*, 260-263.

Palmer, S. E. (1975). The effects of contextual scenes on the identification of objects. *Memory & Cognition, 3,* 519-526.

Petersen, S. E., Fox, P. T., Posner, M. I., Mintun, M., & Raichle, M. E. (1988). Positron emission tomographic studies of the processing of single words. *Journal of Cognitive Neuroscience, 1,* 153-170.

Posner, M. I. (1980). Orienting of attention. *The Quarterly Journal of Experimental Psychology, 32*, 3-25.

Posner, M. I. (1992). Attention as a cognitive and neural system. *Current Directions in Psychological Science, 1,* 11-14.

Posner, M. I., & Petersen, S. E. (1990). The attention system of the human brain. *Annual Review of Neuroscience, 13,* 25-42.

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

Posner, M. I., Snyder, C. R. R., & Davidson, B. J. (1980). Attention and the detection of signals. *Journal of Experimental Psychology: General, 109,* 160-174.

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

Remington, R. W., Folk, C. L., & McLean, J. P. (2001). Contingent capture or delayed allocation of attention? *Perception & Psychophysics, 63,* 298-307.

Rensink, R. A. (2002). Change detection. *Annual Review of Psychology, 53,* 245-277.

Rensink, R. A., O'Regan, J. K., & Clark, J. J. (1997). To see or not to see: The need for attention to perceive changes in scenes. *Psychological Science, 8,* 368-73.

Rizzolatti, G., Riggio, L., Dascola, I., & Umiltá, C. (1987). Reorienting attention across the horizontal and vertical meridians: Evidence in favor of a premotor theory of attention. *Neuropsychologia, 25*, 31-40.

Rock, I., & Gutman, D. (1981). The effect of inattention on form perception. *Journal of Experimental Psychology: Human Perception and Performance, 7,* 275–285.

Scharlau, I. (2004). Evidence against response bias in temporal order tasks with attention manipulation by masked primes. *Psychological Research*, *68,* 224-236.

Schwarting, I. S., & Johnston, W. A. (1998). Spontaneous attention to primed and nonprimed inputs. *Psychonomic Bulletin & Review, 5*, 295-299.

Simons, D. J., & Levin, D. T. (1998). Failure to detect changes to people during a real-world interaction. *Psychonomic Bulletin & Review, 5,* 644–49.

Soto, D., Heinke, D., Humphreys, G. W., & Blanco, M. J. (2005). Early, involuntary top-down guidance of attention from working memory. *Journal of Experimental Psychology: Human Perception and Performance, 31*, 248–261.

Stelmach, L. W., & Herdman, C. M. (1991). Directed attention and perception of temporal order. *Journal of Experimental Psychology: Human Perception and Performance, 17,* 539-550.

Sternberg, S. (1969). The discovery of processing stages: Extensions of Donder's method. In W. G. Koster (Ed.), *Attention and Performance II* (pp. 51-84). Amsterdam: North-Holland Publishing Company.

Stolz, J. A. (1996). Exogenous orienting does not reflect and encapsulated set of processes. *Journal of Experimental Psychology: Human Perception and Performance, 33*, 187-201.

Stolz, J. A. (1999). Word recognition and temporal order judgments: Semantics turns back the clock. *Canadian Journal of Experimental Psychology*, *53,* 316-322.

Stolz, J. A., & Stevanovski, B. (2004). Interactive activation in visual word recognition: Constraints imposed by the joint effects of spatial attention and semantics. *Journal of Experimental Psychology: Human Perception and Performance, 30,* 1064-1076.

Tanenhaus, M. K., Spivey-Knowlton, M. J., Eberhard, K. M., & Sedivy, J. C. (1995). Integration of visual and linguistic information in spoken language comprehension. *Science*, *268,* 1632-1634.

Theeuwes, J. (1992). Perceptual selectivity for color and form. *Perception & Psychophysics*, *51*, 599–606.

Tipper, S. P. (1985). The negative priming effect: Inhibitory priming by ignored objects. *The Quarterly Journal of Experimental Psychology A: Human Experimental Psychology, 37,* 571-590.

Walter, E., & Dassonville, P. (2005). Semantic guidance of attention within natural scenes. *Visual Cognition, 12,* 1124-1142.

Wolfe, J. (1994). Guided Search 2.0—a revised model of visual search. *Psychonomic Bulletin & Review, 1,* 202–238.

Woodman, G. F., & Luck, S. J. (1999). Electrophysiological measurement of rapid shifts of attention during visual search. *Nature, 400,* 867–869.

Woodman, G. F., & Luck, S. J. (2003). Serial deployment of attention during visual search. *Journal of Experimental Psychology: Human Perception and Performance, 29,* 121-138.

Yantis, S., & Jonides, J. (1984). Abrupt visual onsets and selective attention: Evidence from visual search. *Journal of Experimental Psychology: Human Perception and Performance, 1,* 601–621.

Yantis, S., & Jonides, J. (1990). Abrupt visual onsets and selective attention: Voluntary versus automatic allocation. *Journal of Experimental Psychology: Human Perception and Performance, 16*, 121-134.

Yee, E., & Sedivy, J. C. (2006). Eye movements to pictures reveal transient semantic activation during spoken word recognition. *Journal of Experimental Psychology: Learning, Memory and Cognition, 32,* 1-14.

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