Basic Processes in Reading:

Spatial Attention as a Necessary Preliminary to Lexical/Semantic Processing

by

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Author's Declaration

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

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Stephanie Waechter

Abstract

The question of whether words can be identified *without spatial attention* has been a topic of considerable interest over the last five and a half decades, but the literature has yielded mixed conclusions. Some studies show substantial effects of distractor words which are argued to appear outside of spatial attention, whereas a small number of other studies show no evidence of such effects. I argue that at least some of the discrepant results can be understood in terms of failures to optimally focus attention at the cued location. The present experiments manipulated the proportion of valid trials to encourage distributed (Experiments 1 and 3) or focused (Experiments 2 and 4) spatial attention. Participants read aloud a target word, and the impact of a simultaneously presented distractor word was assessed. Semantic and repetition distractor effects were present when conditions promoted distributed spatial attention, but distractor effects were absent when conditions promoted focused spatial attention. These data are consistent with the proposal that (1) the allocation of spatial attention across displays is strongly context-dependent and (2) spatial attention is a necessary preliminary to lexical/semantic processing.

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Dedication

To my parents—For their unfailing patience, understanding, and support.

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Introduction

The debate over the locus of selective "attention" has been one of the most intense and long-standing controversies in cognitive psychology, dating back to Broadbent's (1958) seminal work (see Lachter, Forster, & Ruthruff, 2004 for a review). In particular, the issue of whether visually presented *words* can be processed outside the focus of spatial attention (operationalized in terms of spatial cueing) is still debated by many. The majority of researchers favour the view that spatial attention is not a necessary preliminary for visual word identification to begin (perhaps because of the belief that visual word recognition is "automatic"). Our working assumption is that the experiments that have sought to address this question have often failed to provide the conditions that allow for a strong test of this claim.

Four experiments are reported that examine the role of spatial attention when reading target words aloud (with accompanying distractor words simultaneously present in the visual field) under conditions that promote distributed versus focused spatial attention. When the proportion of validly cued trials is low, promoting distributed processing across target and distractor locations, effects of the nominally unattended distractors are evident. When the proportion of validly cued trials is high, promoting processing that is more spatially focused, distractor effects are eliminated. I therefore conclude that (1) spatial attention is a necessary preliminary to lexical/semantic processing, and (2) that previous results consistent with the hypothesis that spatial attention is *not* a necessary preliminary to such processing are best understood as failures to ensure that spatial attention is firmly focused on the target location. I begin by considering some of the literature on this topic.

Previous findings

In a landmark study, McCann, Folk, and Johnston (1992) crossed the spatial cueing paradigm (Posner, 1980) with a lexical decision task. Participants performed speeded lexical decisions on high-frequency words, low-frequency words, and nonwords. The words were presented above or below fixation and were preceded by a valid (same location as the target) or invalid (opposite location of the target) exogenous cue. McCann and colleagues argued that if spatial attention was necessary to process these stimuli, then spatially cueing the location at which the stimulus was to appear (valid location) should result in faster responses than spatially cueing a different (invalid) location. In contrast, if the stimuli *could* be processed outside of the focus of spatial attention, then spatial cueing would have little or no effect. That is, processing would occur unimpeded regardless of the location of spatial attention. McCann et al. also considered the possibility that the need for spatial attention might be dependent upon how familiar the stimuli were, with very familiar items (e.g., high frequency words) needing little or no spatial attention as compared to less familiar items (low frequency words or nonwords). Across several experiments, McCann et al. (1992) reported a main effect of spatial cueing and main effects of word frequency and lexicality (words versus nonwords), but no interaction between the effects of familiarity and cue validity. They therefore concluded that spatial attention as indexed by the spatial cueing procedure is necessary for word identification to occur. Other studies using spatial cueing have yielded consistent results (e.g., Stolz & McCann, 2000; Stolz & Stevanovski, 2004).

Several other paradigms have been used in attempts to determine if words can be processed outside of spatial attention. These investigations have led to the conclusion that spatial attention is *not* a necessary preliminary to lexical-semantic processing of visually presented words, in direct disagreement with the conclusion drawn by McCann et al. (1992).

The paradigms that have been recruited to investigate the necessity of spatial attention for word processing include the Stroop paradigm (e.g., Kahneman & Henik, 1981; Van der Heijden, Hagenaar, & Bloem, 1984; Lachter, Ruthruff, Lien, & McCann, 2008), flanker paradigm (e.g., Shaffer & LaBerge, 1979; Guttentag, Haith, Goodman, & Hauch, 1984) and priming paradigm (e.g., Lachter, Forster, & Ruthruff, 2004; Besner, Risko, and Sklair, 2005). A methodological point common to all these paradigms is that participants are asked to attend to one stimulus and ignore a word present elsewhere in the display (though in several of these cases the distractor word was actually a "prime" that appears prior to a singleton target, as in Besner et al., 2005; Lachter et al. 2004). When the "ignored" word influences responses to the attended stimulus, then the ignored word is said to have been processed without spatial attention. When the ignored word does not influence responses to the attended stimulus, it is argued that the ignored word was not processed, thus supporting the conclusion that spatial attention was necessary for word processing to occur.

These studies have produced mixed results. For example, Brown, Gore, and Carr (2002) found interference from irrelevant colour words in a simultaneous display even when the target colour bar was validly cued. Risko, Stolz, and Besner (2005), however, found no evidence of interference from irrelevant colour words in a visual search experiment.

Failures of selective attention

The disparate results from Brown et al. (2002) and Risko et al. (2005), as well as many of the other mixed results in this literature, may be explained by poor experimental control over spatial attention. For example, the targets in Brown et al. (2002) appeared in one of three locations and the spatial cues were of low validity (Experiments 1-3) or always appeared in the same location (Experiments 4 and 5). In contrast, the targets in Risko et al. (2005) appeared in one of 16 possible locations, leading to a much greater degree of spatial uncertainty. Risko et al. (2005) therefore suggested that insufficient spatial uncertainty, among other factors, may have led to failures of selective attention in the Brown et al. (2002) experiments.

Indeed, it is a curious fact that the work by investigators who primarily study attention has had remarkably little impact on those who study the effects of attention on visual word recognition. Yantis and Johnston (1990) note that:

> Information from to-be-ignored locations could become available past the locus of selection because of imperfections in the selective process itself (e.g., the spatial extent of the attentional focus encompasses a to-be-ignored object) or the way in which it is controlled (e.g., a subject occasionally mislocalizes a cue) (p. 136).

That is, effects from to-be-ignored words may represent a failure to optimally capture attention at the spatial location of interest, rather than reflecting the processing of words without attention. For example, Lachter et al. (2008) concluded that spatial attention is not a necessary preliminary to visual word identification, but in their experiments the target always appeared at fixation. This leaves open the possibility that subjects' attention wandered at least some of the time in order to explore other locations where stimuli (such as the prime words) appeared.

Yantis and Johnston outline a number of strategies for optimizing selective attention. Among other suggestions they emphasize the use of (a) 100% valid cues and (b) target locations that vary from trial to trial.

Interestingly, few experiments in this literature use spatial cues to manipulate the focus of spatial attention. Of those that do, the experiments that show evidence of processing without spatial attention use cue validities of less than 100%, *and* present either multiple items in the target display (e.g., Brown et al., 2002) or a prime display coupled with a target display (e.g., Besner, Risko, & Sklair, 2005). In the Besner et al. (2005) experiments, both a spatial cue and a prime word were presented; the prime word always appeared in a location other than the target and was quickly masked. The target that followed was either related (the same word) or unrelated (a different word) to the prime. Besner et al. (2005) found significant priming effects when cue validity was 50%, but no priming effects when cue validity was 100%. Besner and colleagues concluded that participants actively distributed attention in different ways depending on cue validity. When cues were uninformative as to target location (50% valid), participants distributed their attention across the display and the prime was processed; this resulted in significant priming effects. When the cues were informative (100% valid), participants focused spatial attention on fixation until the cue appeared (preventing processing of the prime) and then shifted attention to the cued location to process the target.

Although Besner and colleagues' explanation is consistent with the data, it relies on assumptions about the allocation of attention during *prime* processing. Traditionally, experiments on spatial attention and word identification have focused on the processing of target stimuli in the simultaneous presence of distractors. Besner et al. (2005) therefore does not inform us about the distribution of spatial attention when distractors and targets are present at the same time. The experiments reported here address this issue.

The present experiments

The purpose of Experiments 1 and 2 is to determine how semantically related and unrelated words, presented as distractors in the target display, affect the processing of target words under two conditions of spatial cueing. In these experiments, a target word and a distractor word are presented simultaneously on the screen. The target word is distinguished from the distractor word by colour (either red or blue). Participants are instructed to read the target word aloud on each trial. Critically, the words are preceded by an abrupt onset cue in order to manipulate the focus of spatial attention. In Experiment 1, the cue is valid on 50% of trials, which should encourage the distribution of spatial attention across the display. I therefore expect the semantic relatedness of the distractor word to affect target processing. In contrast, in Experiment 2, cue validity is 100%, which should maximize focused spatial attention. If this is so, and distractor words cannot be read in the absence of spatial attention, then the semantic relatedness effect should be eliminated.

Experiment 1

Method

Participants. Forty undergraduate students from the University of Waterloo participated in this experiment in exchange for course credit. All participants spoke English as their first language and had normal or corrected-to-normal vision.

Design. This experiment employed a 2 (Cue Validity: Valid versus Invalid) x 2 (Relatedness: Semantically Related versus Unrelated) within-participants design.

Stimuli. Two hundred semantically related distractor-target pairs were used in Experiment 1. These words were taken from the Stolz, Besner, and Carr (2005) stimulus set. In order to create the desired relatedness proportion of .25, each distractor-target pair was assigned to one of four word lists. Each list consisted of 50 related distractor-target pairs, and the targets were matched across lists for letter length, frequency, and orthographic neighbourhood size. One of these lists comprised the **related** item pairs for one of four counterbalanced conditions. In order to create the unrelated pairs, the distractors from the remaining lists were randomly re-paired with different targets. Therefore, across participants, each target appeared in both the related and the unrelated conditions.

An additional 20 distractor-target pairs were created for practice trials. Five pairs were semantically related; 15 pairs were semantically unrelated.

Procedure. Participants were tested individually, seated approximately 50 cm from a 15-inch computer monitor. Task instructions were displayed on the monitor and were also relayed verbally.

Stimulus display and response collection were controlled by E-Prime software (Psychology Software Tools). Practice trials were administered, followed by the experiment trials. A self-paced rest break was given halfway through the experiment, after 100 trials.

Stimuli were presented in light colours against a black background. Each trial began with a grey fixation symbol (+) displayed in the center of the screen for 500 ms. Participants were asked to fixate on the symbol and to avoid making eye movements throughout the experiment. Then an abrupt onset cue, consisting of a white rectangle 2 cm wide by 1 cm tall, appeared 2.5 cm above or below fixation for 50 ms. The proportion of valid trials was .50, and the assignment of valid or invalid cues to targets was counterbalanced across participants. The cue was followed by a 50 ms interval with only the fixation cross on the screen.

Next, the target display appeared. The target display consisted of two words (the target and the distractor), both presented in size 14 Courier New font. The words appeared simultaneously above and below fixation, and .5 cm (.57 degrees of visual angle) of blank display separated the nearest edge of the fixation cross from each of the words. One word appeared in red and the other appeared in blue. The colour of the target words was counterbalanced across participants. The participants' task was to read aloud the word of their assigned colour (i.e., "read the red word on each trial" or "read the blue word on each trial") as quickly and accurately as possible. The target stimulus remained on the screen until participants made a response. Response times (RTs, to the nearest millisecond) were recorded. The display then disappeared, and the experimenter coded the participant's vocal response as correct, incorrect, or a microphone error before the next trial began.

Results

A small number of trials (2.6% of total) were discarded due to microphone errors. The RT analysis was conducted for trials on which a correct pronounciation was provided. RTs falling more than 2.5 standard deviations from the mean for each subject and condition were removed. Outlier removal resulted in the exclusion of 1.8% of correct RT data. Mean RTs and percent errors for each condition are shown in Table 1. Data were subjected to a 2 (Cue Validity: Valid versus Invalid) x 2 (Relatedness: Semantically Related versus Unrelated) repeated measures ANOVA.

RTs

There was a main effect of Cue Validity, F (1, 39) = 81.84, MSE = 47093, $p < .001$, such that participants responded more quickly to validly cued targets (M = 610 ms) than to invalidly cued targets (M = 644 ms). There was also a main effect of Relatedness, F (1, 39) = 41.93, MSE = 11006, $p < .01$, such that participants responded more quickly to related targets (619 ms) than to unrelated targets (635 ms). There was no Cue Validity by Relatedness interaction, F (1, 39) < 1; that is, there was no difference in the size of the relatedness effect for validly cued (16 ms) and invalidly cued (18 ms) trials.

Errors

There was a marginally significant main effect of Cue Validity, F (1, 39) = 3.48, MSE = .002, p = .07, such that participants made more errors on invalidly cued trials (M = 2.0%) than on validly cued trials (M = 1.4%). There was no effect of Relatedness ($F < 1$). There was no Cue Validity by Relatedness interaction, F (1, 39) = 1.59, p > .20.

TABLE 1

Mean Response Times (RTs; in ms) and Errors (%) by Experiment, Cue Validity, and Relatedness

	Semantically Related Versus Unrelated Distractors				**Same Word Versus Unrelated Distractors**			
	Experiment 1 (50% Valid)		*Experiment 2 (100% Valid)*		*Experiment 3 (50% Valid)*		*Experiment 4 (100% Valid)*	
	Invalid	*Valid*	*Invalid*	*Valid*	*Invalid*	*Valid*	*Invalid*	*Valid*
RTs								
Unrelated	652	619	--	617	718	685	--	661
Related	636	601	--	616	703	677	--	659
Difference	**16**	**18**	--	**1**	**15**	**8**	--	**2**
Errors								
Unrelated	2.2	1.2	--	1.6	6.7	9.2	--	7.5
Related	1.9	1.7	--	1.5	7.0	6.5	--	6.3
Difference	**0.3**	**-0.5**	--	**0.1**	**-0.3**	**2.7**	--	**1.1**

Discussion

Experiment 1 examined the effect of semantically related and unrelated distractor words on the processing of a target word when the target was validly cued on 50% of trials. The relatedness effect was the same size for valid trials as for invalid trials, suggesting that the distractor word was processed to the semantic level even on trials in which the target word was validly cued.

Experiment 2

In Experiment 2, cue validity was set at 100% in order to encourage focused spatial attention. If spatial attention is now properly focused *and* if spatial attention is a necessary preliminary to semantic processing, then the effect of related distractors on target processing should be eliminated.

Method

Participants. Thirty-two undergraduate students from the University of Waterloo participated in this experiment in exchange for course credit. All participants spoke English as their first language and had normal or corrected-to-normal vision. None had participated in Experiment 1.

Stimuli. The stimuli were identical to those of Experiment 1.

Procedure. The procedure was identical to that of Experiment 1, except that targets were always validly cued.

Results

A small number of trials (1.5% of total) were discarded due to microphone errors. The RT analysis was conducted for experimental trials on which a correct pronunciation was provided. RTs falling more than 2.5 standard deviations from the mean for each subject and condition were again removed. Outlier removal resulted in the exclusion of 2.6% of correct RT data. Mean RTs and percent errors for related and unrelated trials are shown in Table 1. Paired t-tests were conducted to test for an effect of relatedness.

There were no differences in RTs between related (616 ms) and unrelated (617 ms) trials, t (31) < 1. There were no differences in errors between related (1.5%) and unrelated (1.6%) trials, t (31) < 1.

Discussion

Experiment 2 increased cue validity to 100% in order to encourage focused spatial attention to the target location. The significant relatedness effect (16 ms) observed in Experiment 1 was eliminated. In other words, there was no evidence that distractors affected target processing in Experiment 2. Spatial attention thus appears to be a necessary preliminary for semantic processing.

Experiment 3

Experiment 2 provides evidence that spatial attention is a necessary preliminary to the *semantic* processing of words. However, all current theories of visual word recognition (e.g., Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001; Perry, Zeigler, & Zorzi, 2007; Plaut, McClelland, Seidenberg, & Patterson, 1996) distinguish between semantic processing and pre-semantic levels of processing. Spatial attention may be a necessary preliminary for the semantic processing of words, but it may also be a necessary preliminary for the nonsemantic processing that precedes semantic processing.

Experiments 3 and 4 therefore address the issue of whether spatial attention is a necessary preliminary for *lexical* (word level) processing. In these experiments, the distractor word was either the same as the target word (related) or a different (unrelated) word. If spatial attention is a necessary preliminary for lexical level processing, there should be a (lexically-based) relatedness effect when spatial attention is distributed (Experiment 3), and this relatedness effect should be eliminated when spatial attention is focused (Experiment 4). If spatial attention is a necessary preliminary for semantic-level processing but not lexical level processing, then the lexically-based distractor effect should remain despite focused spatial attention in Experiment 4.

Method

Participants. Forty undergraduate students from the University of Waterloo participated in this experiment in exchange for course credit. All participants spoke English as their first language and had normal or corrected-to-normal vision. None had participated in Experiment 1 or Experiment 2.

Stimuli. The stimuli for Experiment 3 consisted of 175 words with irregular pronunciations (e.g., have, wand, pint). One hundred of these words were taken from Besner, Reynolds, and O'Malley (in press); the remaining 75 words came from the Dual Route Cascaded Model's pool of monosyllabic irregular words (Coltheart et al., 2001). In order to create the desired relatedness proportion of .25, each word was assigned to one of seven word lists. Each list consisted of 25 words, which were matched across lists for letter length, frequency, and orthographic neighbourhood size. One list comprised the **related** pairs for each of the counterbalance conditions. For the related pairs, the same word was used as both the target and distractor.

To create the **unrelated** pairs, the remaining word lists were re-paired such that words from one list comprised the targets and words from another list comprised the distractors, resulting in 75 unrelated distractor-target pairs. Therefore, across participants, each target appeared in both the related and the unrelated conditions.

One word was presented in uppercase and the other word was presented in lowercase on each trial. For half of the trials, the target was in uppercase and the distractor was in lowercase; for the other half of trials, the distractor was in uppercase and the target was in lowercase. The assignment of distractors and targets to case condition was counterbalanced across participants.

An additional 20 word-prime, word-target pairs were created for practice trials. Five trials consisted of related targets and distractors; 15 trials consisted of unrelated targets and distractors.

Procedure. The procedure was identical to Experiment 1.

Results

A small number of trials (4.2% of total) were discarded due to microphone errors. The RT analysis was conducted for experimental trials on which a correct pronounciation was provided. RTs falling more than 2.5 standard deviations from the mean for each subject and condition were again removed. Outlier removal resulted in the exclusion of 2.0% of correct RT data. Four participants yielded extreme relatedness effects (more than 2.5 standard deviations from the mean) in the valid or invalid cueing condition (e.g., relatedness effects of -109 or 160 ms). The data from these four participants were excluded from further RT analyses.

Mean RTs and percent errors for related and unrelated trials are shown in Table 1. The data were subjected to a 2 (Cue Validity: Valid versus Invalid) x 2 (Relatedness: Same Word Distractor versus Different Word Distractor) repeated measures ANOVA.

*RT*s

There was a main effect of Cue Validity, F (1, 35) = 22.74, MSE = 1383, $p < .001$, such that participants responded more quickly to validly cued targets (681 ms) than to invalidly cued targets (711 ms). There was also a main effect of Relatedness, F (1, 35) = 5.84, MSE = 823, $p < .05$, such that participants responded more quickly to related targets (690 ms) than to unrelated targets (702 ms). There was no Cue Validity by Relatedness interaction ($F < 1$).

Errors

There was no main effect of Cue Validity, ($F < 1$). There was no effect of Relatedness, F (1, 39) = 2.09, MSE = .003, p = .156. The Cue Validity x Relatedness interaction was not significant, F (1, 39) = 2.48, MSE = .004, p = .124.

Discussion

Experiment 3 examined the effect of distractor words that were the same as (related) or different from (unrelated) the target word. The target was validly cued on 50% of trials. There was a significant main effect of relatedness, but no interaction between the effects of relatedness and cue validity. In other words, the data are consistent with the conclusion that the distractor word was processed to the lexical level even on trials on which the target word was validly cued.

Experiment 4

Experiment 4 increased cue validity to 100% in order to encourage focused spatial attention. If spatial attention is now properly focused *and* if spatial attention is a necessary preliminary to lexical processing, then the effect of related distractors on target processing should be eliminated.

Method

Participants. Forty undergraduate students from the University of Waterloo participated in this experiment in exchange for course credit. All participants spoke English as their first language and had normal or corrected-to-normal vision. None had participated in Experiments 1, 2, or 3.

Stimuli. The stimuli were identical to those in Experiment 3.

Procedure. The procedure was identical to that of Experiment 3, except that all targets were validly cued.

Results

A small number of trials (3.2% of total) were discarded due to microphone errors. The RT analysis was conducted for trials on which a correct pronunciation was provided. RTs falling more than 2.5 standard deviations from the mean for each subject and condition were again removed. Outlier removal resulted in the exclusion of 2.6% of correct RT data. Mean RTs and percent errors for related and unrelated trials are again shown in Table 1.

There were no differences in RTs between related (M = 659 ms) and unrelated (M = 661 ms) trials, t (39) < 1. There were no differences in errors between related (M = 6.3%) and unrelated (M = 7.5%) trials, t (31) = 1.41, p = .164.

Discussion

When cue validity was 100% in Experiment 4, the relatedness effect that was observed in Experiment 3 was eliminated. The simplest conclusion, therefore, is that spatial attention appears to be a necessary preliminary for lexical, as well as semantic, processing.

Cross-experiments analyses

Experiments 1 and 3 examined the effect of a related distractor word on processing of a target when cue validity was 50%. There were significant relatedness effects. Experiments 2 and 4 used the same items but cue validity was 100% instead of 50%. Relatedness effects were now eliminated. A cross-experiment analysis was conducted in order to demonstrate that the relatedness effects observed in Experiments 1 and 3 were significantly larger than the null relatedness effects in Experiments 2 and 4. To this end, a 2 (Relatedness: Related versus Unrelated) x 2 (Experiment Type: 50% Valid versus 100% Valid) mixed ANOVA was conducted for RTs and errors. This analysis included only the validly cued trials in each experiment. The results of this analysis are included in Appendices M and N.

Critically, for RTs there was a significant Relatedness x Experiment interaction, F (1, 146) = 5.24, MSE = 463.8, $p < .05$, such that the relatedness effect was larger for the 50% Cue Validity Experiments (13 ms) than for the 100% Cue Validity Experiments (1.5 ms).

General Discussion

The four experiments reported here examined the impact of related and unrelated distractor words on the time to read aloud target words under a condition that favoured distributed spatial attention (50% valid cues as in Experiments 1 and 3) and a condition that favoured focused spatial attention (100% valid cues as in Experiments 2 and 4). When cues were 50% valid, significant relatedness effects were observed for validly cued targets, demonstrating that the distractor words must have been processed. However, in the two experiments where the cue was 100% valid, there was no significant effect of the distractors in either experiment. I conclude, therefore, that the allocation of attention across the display is context-dependent (consistent with a sizeable literature on this topic; e.g., Eriksen & St. James, 1986; LaBerge, 1983, Yantis & Johnston, 1990). Most importantly, the present results are consistent with the hypothesis that spatial attention is a necessary preliminary to word identification.

The results of the present experiments also converge with those of Musch and Klauer (2001), who used a similar paradigm to investigate the putative automaticity of affective processing in the evaluative decision task. Musch and Klauer (2001) manipulated the focus of spatial attention across groups using a cueing paradigm. In the "distributed attention condition", the cues that preceded the target display were always presented at fixation and never appeared at the target location (0% valid). In the "focused attention condition", the cues that preceded the target display were always presented at the target location (100% valid). Participants were asked to evaluate the affective valence of the target stimulus, while distractors were presented elsewhere in the display. These distractors could be affectively congruent with the target stimulus, affectively neutral, or affectively incongruent with the target stimulus. Participants in the distributed attention condition were significantly more accurate when distractors were congruent compared to when distractors were incongruent, displaying the standard affective congruency effect. However, this effect was eliminated in the focused attention condition. Although the tasks are very different (evaluative judgement versus reading aloud) and Musch and Klauer (2001) did not examine any potential effects in RTs, their data and the present data provide converging evidence: when attention is optimally focused, distractor words presented outside of the focus of spatial attention do not influence target processing.

Summary and Conclusions

The present results demonstrate that when (1) spatial attention is optimally focused (via the use of 100% valid cues) and (2) target location varies across trials rather than being fixed, and (3) targets and distractors are not repeated across trials, the time to read a target word aloud is not affected by semantically or lexically related distractors. These data are consistent with the conclusion that, at least under these conditions, spatial attention is a necessary preliminary to lexical-semantic processing of visually presented words.

Finally, it should be noted that the present results say nothing about the spatial attentional demands of lexical-semantic processing per se. Once processes that need spatial attention are completed (e.g., feature and/or letter level processing), lexical-semantic processing may unfold without any need for spatial attention.

Appendix A:
Participant RT and Error Data from Experiment 1

Experiment 1: Semantically-Related Distractors and 50% Valid Trials

	Mean RT				Mean Percent Errors			
	Invalid Trials		Valid Trials		Invalid Trials		Valid Trials	
Participant #	**Unrelated**	**Related**	**Unrelated**	**Related**	**Unrelated**	**Related**	**Unrelated**	**Related**
1	558	541	542	498	.03	.04	.01	.00
2	634	589	620	555	.00	.04	.00	.00
3	561	555	550	518	.01	.00	.00	.00
4	802	807	764	763	.05	.00	.03	.00
5	603	587	585	593	.01	.00	.00	.00
6	595	568	531	497	.01	.00	.01	.04
7	753	740	735	708	.03	.00	.01	.08
8	641	629	614	598	.01	.00	.01	.04
9	774	722	704	682	.00	.04	.00	.00
10	733	725	698	688	.00	.04	.00	.00
11	646	621	632	599	.01	.00	.00	.00
12	769	799	744	718	.04	.00	.00	.00
13	604	555	546	543	.00	.00	.00	.00
14	574	608	559	529	.00	.00	.00	.04
15	567	540	555	514	.00	.00	.00	.00
16	580	579	539	501	.01	.04	.01	.00
17	640	667	645	596	.03	.00	.00	.00
18	758	725	710	656	.01	.08	.05	.08
19	677	610	637	604	.01	.00	.03	.00
20	619	591	579	593	.04	.08	.06	.04
21	654	667	614	604	.04	.00	.00	.04
22	641	606	599	586	.05	.00	.01	.00
23	598	593	587	600	.09	.13	.03	.00
24	733	728	718	741	.06	.00	.05	.00
25	637	614	612	633	.06	.00	.03	.00
26	565	562	538	548	.03	.04	.01	.04
27	554	527	551	547	.01	.00	.01	.04
28	633	594	557	517	.04	.00	.01	.04
29	664	633	637	619	.03	.00	.00	.00
30	754	747	657	644	.01	.04	.01	.04
31	659	692	635	614	.01	.00	.01	.00
32	588	556	571	549	.01	.00	.01	.00
33	696	676	614	597	.03	.08	.04	.08
34	688	651	630	658	.03	.09	.00	.04
35	609	591	587	601	.00	.00	.00	.00
36	772	749	689	687	.01	.00	.00	.00
37	577	546	539	525	.00	.00	.00	.00
38	685	683	646	644	.00	.04	.01	.04
39	588	585	587	533	.00	.00	.00	.00
40	703	692	684	650	.03	.00	.00	.00
Mean	**652**	**636**	**619**	**601**	**0.022**	**0.019**	**0.012**	**0.017**

Appendix B:
Participant RT and Error Data from Experiment 2

Experiment 2: Semantically-Related Distractors and 100% Valid Trials

	Mean RT				**Mean Percent Errors**			
	Invalid Trials		**Valid Trials**		**Invalid Trials**		**Valid Trials**	
Participant #	**Unrelated**	**Related**	**Unrelated**	**Related**	**Unrelated**	**Related**	**Unrelated**	**Related**
1	-	-	533	533	-	-	.00	.00
2	-	-	633	630	-	-	.01	.02
3	-	-	564	541	-	-	.00	.00
4	-	-	594	591	-	-	.00	.00
5	-	-	606	592	-	-	.01	.00
6	-	-	651	689	-	-	.00	.00
7	-	-	536	536	-	-	.01	.00
8	-	-	590	570	-	-	.02	.00
9	-	-	630	632	-	-	.01	.00
10	-	-	566	550	-	-	.02	.02
11	-	-	549	536	-	-	.00	.00
12	-	-	479	496	-	-	.00	.00
13	-	-	613	604	-	-	.02	.02
14	-	-	628	655	-	-	.03	.02
15	-	-	635	622	-	-	.03	.06
16	-	-	562	590	-	-	.01	.02
17	-	-	567	601	-	-	.01	.00
18	-	-	718	707	-	-	.00	.00
19	-	-	715	683	-	-	.03	.04
20	-	-	649	664	-	-	.03	.04
21	-	-	495	503	-	-	.01	.02
22	-	-	582	551	-	-	.02	.00
23	-	-	761	769	-	-	.02	.04
24	-	-	678	685	-	-	.01	.00
25	-	-	569	569	-	-	.13	.14
26	-	-	695	691	-	-	.01	.00
27	-	-	617	600	-	-	.01	.00
28	-	-	604	591	-	-	.00	.00
29	-	-	615	646	-	-	.01	.00
30	-	-	600	575	-	-	.03	.02
31	-	-	674	715	-	-	.03	.00
32	-	-	827	803	-	-	.02	.02
Mean			**617**	**616**			**0.016**	**0.015**

Appendix C:
Participant RT and Error Data from Experiment 3

Experiment 3: Lexically-Related Distractors and 50% Valid Trials

	Mean RT				**Mean Percent Errors**			
	Invalid Trials		**Valid Trials**		**Invalid Trials**		**Valid Trials**	
Participant #	**Unrelated**	**Related**	**Unrelated**	**Related**	**Unrelated**	**Related**	**Unrelated**	**Related**
1	863	813	845	905	.03	.04	.07	.04
2*	963	1104	942	896	.12	.08	.07	.00
3	855	838	748	776	.07	.00	.14	.23
4	765	683	672	672	.23	.07	.24	.21
5	800	802	772	822	.11	.07	.13	.14
6	609	646	633	592	.02	.00	.02	.00
7	618	664	605	586	.02	.00	.02	.07
8	717	713	693	714	.03	.13	.03	.09
9	639	638	605	596	.11	.00	.07	.08
10	765	721	700	736	.08	.00	.20	.00
11	932	821	754	759	.18	.21	.14	.08
12	625	636	579	549	.05	.13	.10	.00
13	690	623	599	603	.14	.07	.09	.07
14	863	884	898	958	.12	.13	.20	.14
15	684	631	662	626	.00	.17	.05	.14
16	648	717	607	611	.10	.21	.08	.08
17	771	685	701	624	.07	.23	.05	.00
18	680	676	691	680	.00	.00	.04	.00
19	696	673	681	650	.04	.00	.02	.00
20	837	831	789	745	.02	.00	.04	.21
21	757	744	661	654	.05	.07	.07	.00
22	849	866	822	840	.07	.07	.07	.08
23	794	817	764	794	.07	.00	.10	.07
24	618	627	666	617	.07	.00	.07	.00
25*	795	635	711	694	.31	.33	.27	.00
26	621	604	665	558	.02	.07	.11	.00
27	731	713	707	755	.14	.00	.12	.07
28	656	675	649	692	.00	.20	.11	.00
29*	697	685	590	699	.00	.08	.10	.00
30	757	727	720	664	.07	.00	.11	.15
31	723	706	689	660	.09	.08	.10	.13
32	659	614	615	600	.00	.00	.04	.07
33	673	663	630	614	.04	.00	.05	.07
34	658	653	704	622	.02	.07	.07	.00
35	631	632	591	605	.02	.00	.00	.00
36*	738	911	722	703	.02	.07	.11	.08
37	680	643	589	623	.07	.07	.14	.13
38	648	602	645	645	.05	.00	.02	.14
39	671	683	657	624	.02	.07	.02	.00
40	674	655	663	606	.00	.08	.19	.00
Mean	**718**	**703**	**685**	**677**	**0.067**	**0.070**	**0.092**	**0.065**

*Participant excluded from RT analysis due to extreme priming score

Appendix D:
Participant RT and Error Data from Experiment 4

Experiment 4: Lexically-Related Distractors and 100% Valid Trials

	Mean RT				Mean Percent Errors			
	Invalid Trials		Valid Trials		Invalid Trials		Valid Trials	
Participant #	**Unrelated**	**Related**	**Unrelated**	**Related**	**Unrelated**	**Related**	**Unrelated**	**Related**
1	-	-	618	653	-	-	.05	.00
2	-	-	691	715	-	-	.04	.17
3	-	-	659	672	-	-	.03	.08
4	-	-	824	855	-	-	.04	.09
5	-	-	707	674	-	-	.14	.08
6	-	-	652	688	-	-	.22	.16
7	-	-	607	619	-	-	.07	.00
8	-	-	678	653	-	-	.05	.04
9	-	-	686	701	-	-	.11	.17
10	-	-	593	581	-	-	.04	.04
11	-	-	472	474	-	-	.14	.13
12	-	-	648	624	-	-	.03	.04
13	-	-	576	575	-	-	.04	.00
14	-	-	636	603	-	-	.04	.04
15	-	-	706	726	-	-	.07	.04
16	-	-	784	809	-	-	.06	.08
17	-	-	591	569	-	-	.07	.05
18	-	-	507	501	-	-	.04	.04
19	-	-	769	713	-	-	.26	.16
20	-	-	634	631	-	-	.08	.12
21	-	-	707	668	-	-	.11	.04
22	-	-	904	965	-	-	.15	.22
23	-	-	584	631	-	-	.07	.05
24	-	-	536	551	-	-	.03	.00
25	-	-	751	713	-	-	.17	.09
26	-	-	716	676	-	-	.03	.04
27	-	-	715	707	-	-	.03	.00
28	-	-	659	639	-	-	.05	.00
29	-	-	766	789	-	-	.12	.00
30	-	-	676	703	-	-	.04	.04
31	-	-	698	703	-	-	.08	.12
32	-	-	522	509	-	-	.01	.00
33	-	-	569	557	-	-	.05	.04
34	-	-	615	561	-	-	.11	.12
35	-	-	591	606	-	-	.09	.08
36	-	-	646	704	-	-	.11	.04
37	-	-	693	689	-	-	.00	.04
38	-	-	702	678	-	-	.03	.00
39	-	-	654	656	-	-	.04	.08
40	-	-	706	614	-	-	.04	.00
Mean			**661**	**659**			**0.075**	**0.063**

Appendix E:
2 (Cue Validity: Valid Versus Invalid) x 2 (Relatedness: Semantically Related versus Unrelated) ANOVA on Participant RTs in Experiment 1

Tests of Within-Subjects Effects

Measure:MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
validity	Sphericity Assumed	47093.906	1	47093.906	81.841	.000
	Greenhouse-Geisser	47093.906	1.000	47093.906	81.841	.000
	Huynh-Feldt	47093.906	1.000	47093.906	81.841	.000
	Lower-bound	47093.906	1.000	47093.906	81.841	.000
Error(validity)	Sphericity Assumed	22441.844	39	575.432		
	Greenhouse-Geisser	22441.844	39.000	575.432		
	Huynh-Feldt	22441.844	39.000	575.432		
	Lower-bound	22441.844	39.000	575.432		
relatedness	Sphericity Assumed	11005.806	1	11005.806	41.933	.000
	Greenhouse-Geisser	11005.806	1.000	11005.806	41.933	.000
	Huynh-Feldt	11005.806	1.000	11005.806	41.933	.000
	Lower-bound	11005.806	1.000	11005.806	41.933	.000
Error(relatedness)	Sphericity Assumed	10235.944	39	262.460		
	Greenhouse-Geisser	10235.944	39.000	262.460		
	Huynh-Feldt	10235.944	39.000	262.460		
	Lower-bound	10235.944	39.000	262.460		
validity * relatedness	Sphericity Assumed	18.906	1	18.906	.072	.789
	Greenhouse-Geisser	18.906	1.000	18.906	.072	.789
	Huynh-Feldt	18.906	1.000	18.906	.072	.789
	Lower-bound	18.906	1.000	18.906	.072	.789
Error(validity*relatedness)	Sphericity Assumed	10178.844	39	260.996		
	Greenhouse-Geisser	10178.844	39.000	260.996		
	Huynh-Feldt	10178.844	39.000	260.996		
	Lower-bound	10178.844	39.000	260.996		

Appendix F:
2 (Cue Validity: Valid versus Invalid) x 2 (Relatedness: Semantically Related versus Unrelated) ANOVA on Participant Errors in Experiment 1

Tests of Within-Subjects Effects

Measure:MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
validity	Sphericity Assumed	.002	1	.002	3.479	.070
	Greenhouse-Geisser	.002	1.000	.002	3.479	.070
	Huynh-Feldt	.002	1.000	.002	3.479	.070
	Lower-bound	.002	1.000	.002	3.479	.070
Error(validity)	Sphericity Assumed	.017	39	.000		
	Greenhouse-Geisser	.017	39.000	.000		
	Huynh-Feldt	.017	39.000	.000		
	Lower-bound	.017	39.000	.000		
relatedness	Sphericity Assumed	.000	1	.000	.332	.568
	Greenhouse-Geisser	.000	1.000	.000	.332	.568
	Huynh-Feldt	.000	1.000	.000	.332	.568
	Lower-bound	.000	1.000	.000	.332	.568
Error(relatedness)	Sphericity Assumed	.021	39	.001		
	Greenhouse-Geisser	.021	39.000	.001		
	Huynh-Feldt	.021	39.000	.001		
	Lower-bound	.021	39.000	.001		
validity * relatedness	Sphericity Assumed	.001	1	.001	1.589	.215
	Greenhouse-Geisser	.001	1.000	.001	1.589	.215
	Huynh-Feldt	.001	1.000	.001	1.589	.215
	Lower-bound	.001	1.000	.001	1.589	.215
Error(validity*relatedness)	Sphericity Assumed	.013	39	.000		
	Greenhouse-Geisser	.013	39.000	.000		
	Huynh-Feldt	.013	39.000	.000		
	Lower-bound	.013	39.000	.000		

Appendix G:
Paired t-test (Semantically Related versus Unrelated Trials) on Participant RTs in Experiment 2

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Pair 1	valid_unrel - valid_rel	.46875	20.51118	3.62590	-6.92632	7.86382	.129	31	.898

Appendix H:
Paired t-test (Semantically Related versus Unrelated Trials) on Participant Errors in Experiment 2

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Pair 1	valid_unrel - valid_rel	.00188	.01203	.00213	-.00246	.00621	.882	31	.385

Appendix I:
2 (Cue Validity: Valid versus Invalid) x 2 (Relatedness: Semantically Related versus Unrelated) ANOVA on Participant RTs in Experiment 3

Tests of Within-Subjects Effects

Measure:MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
validity	Sphericity Assumed	31447.111	1	31447.111	22.740	.000
	Greenhouse-Geisser	31447.111	1.000	31447.111	22.740	.000
	Huynh-Feldt	31447.111	1.000	31447.111	22.740	.000
	Lower-bound	31447.111	1.000	31447.111	22.740	.000
Error(validity)	Sphericity Assumed	48401.889	35	1382.911		
	Greenhouse-Geisser	48401.889	35.000	1382.911		
	Huynh-Feldt	48401.889	35.000	1382.911		
	Lower-bound	48401.889	35.000	1382.911		
relatedness	Sphericity Assumed	4807.111	1	4807.111	5.838	.021
	Greenhouse-Geisser	4807.111	1.000	4807.111	5.838	.021
	Huynh-Feldt	4807.111	1.000	4807.111	5.838	.021
	Lower-bound	4807.111	1.000	4807.111	5.838	.021
Error(relatedness)	Sphericity Assumed	28820.889	35	823.454		
	Greenhouse-Geisser	28820.889	35.000	823.454		
	Huynh-Feldt	28820.889	35.000	823.454		
	Lower-bound	28820.889	35.000	823.454		
validity * relatedness	Sphericity Assumed	413.444	1	413.444	.569	.456
	Greenhouse-Geisser	413.444	1.000	413.444	.569	.456
	Huynh-Feldt	413.444	1.000	413.444	.569	.456
	Lower-bound	413.444	1.000	413.444	.569	.456
Error(validity*relatedness)	Sphericity Assumed	25427.556	35	726.502		
	Greenhouse-Geisser	25427.556	35.000	726.502		
	Huynh-Feldt	25427.556	35.000	726.502		
	Lower-bound	25427.556	35.000	726.502		

Appendix J:
2 (Cue Validity: Valid versus Invalid) x 2 (Relatedness: Semantically Related versus Unrelated) ANOVA on Participant Errors in Experiment 3

Tests of Within-Subjects Effects

Measure:MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
validity	Sphericity Assumed	.004	1	.004	.949	.336
	Greenhouse-Geisser	.004	1.000	.004	.949	.336
	Huynh-Feldt	.004	1.000	.004	.949	.336
	Lower-bound	.004	1.000	.004	.949	.336
Error(validity)	Sphericity Assumed	.152	39	.004		
	Greenhouse-Geisser	.152	39.000	.004		
	Huynh-Feldt	.152	39.000	.004		
	Lower-bound	.152	39.000	.004		
relatedness	Sphericity Assumed	.006	1	.006	2.090	.156
	Greenhouse-Geisser	.006	1.000	.006	2.090	.156
	Huynh-Feldt	.006	1.000	.006	2.090	.156
	Lower-bound	.006	1.000	.006	2.090	.156
Error(relatedness)	Sphericity Assumed	.110	39	.003		
	Greenhouse-Geisser	.110	39.000	.003		
	Huynh-Feldt	.110	39.000	.003		
	Lower-bound	.110	39.000	.003		
validity * relatedness	Sphericity Assumed	.009	1	.009	2.475	.124
	Greenhouse-Geisser	.009	1.000	.009	2.475	.124
	Huynh-Feldt	.009	1.000	.009	2.475	.124
	Lower-bound	.009	1.000	.009	2.475	.124
Error(validity*relatedness)	Sphericity Assumed	.149	39	.004		
	Greenhouse-Geisser	.149	39.000	.004		
	Huynh-Feldt	.149	39.000	.004		
	Lower-bound	.149	39.000	.004		

Appendix K:
Paired t-test (Semantically Related versus Unrelated Trials) on Participant RTs in Experiment 4

Paired Samples Test

		Paired Differences							
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper	t	df	Sig. (2-tailed)
Pair 1	valid_unrel - valid_rel	2.32500	32.40084	5.12302	-8.03729	12.68729	.454	39	.652

Appendix L:
Paired t-test (Semantically Related versus Unrelated Trials) on Participant Errors in Experiment 4

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Pair 1	valid_unrel - valid_rel	.01125	.05019	.00794	-.00480	.02730	1.418	39	.164

Appendix M:
2 (Relatedness: Related versus Unrelated) x 2 (Experiment Type: 50% Valid versus 100% Valid) Mixed ANOVA on RTs for Cross-Experiment Comparison

Tests of Within-Subjects Effects

Measure:MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
relatedness	Sphericity Assumed	3865.650	1	3865.650	8.334	.004
	Greenhouse-Geisser	3865.650	1.000	3865.650	8.334	.004
	Huynh-Feldt	3865.650	1.000	3865.650	8.334	.004
	Lower-bound	3865.650	1.000	3865.650	8.334	.004
relatedness * Experiment_Validity	Sphericity Assumed	2428.083	1	2428.083	5.235	.024
	Greenhouse-Geisser	2428.083	1.000	2428.083	5.235	.024
	Huynh-Feldt	2428.083	1.000	2428.083	5.235	.024
	Lower-bound	2428.083	1.000	2428.083	5.235	.024
Error(relatedness)	Sphericity Assumed	67717.441	146	463.818		
	Greenhouse-Geisser	67717.441	146.000	463.818		
	Huynh-Feldt	67717.441	146.000	463.818		
	Lower-bound	67717.441	146.000	463.818		

Tests of Between-Subjects Effects

Measure:MEASURE_1
Transformed Variable:Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Intercept	1.220E8	1	1.220E8	8692.639	.000
Experiment_Validity	664.217	1	664.217	.047	.828
Error	2048745.010	146	14032.500		

Appendix N:
2 (Relatedness: Related versus Unrelated) x 2 (Experiment Type: 50% Valid versus 100% Valid) Mixed ANOVA on Errors for Cross-Experiment Comparison

Tests of Within-Subjects Effects

Measure:MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
relatedness	Sphericity Assumed	.003	1	.003	2.416	.122
	Greenhouse-Geisser	.003	1.000	.003	2.416	.122
	Huynh-Feldt	.003	1.000	.003	2.416	.122
	Lower-bound	.003	1.000	.003	2.416	.122
relatedness * Experiment_Validity	Sphericity Assumed	6.125E-5	1	6.125E-5	.053	.819
	Greenhouse-Geisser	6.125E-5	1.000	6.125E-5	.053	.819
	Huynh-Feldt	6.125E-5	1.000	6.125E-5	.053	.819
	Lower-bound	6.125E-5	1.000	6.125E-5	.053	.819
Error(relatedness)	Sphericity Assumed	.170	146	.001		
	Greenhouse-Geisser	.170	146.000	.001		
	Huynh-Feldt	.170	146.000	.001		
	Lower-bound	.170	146.000	.001		

Tests of Between-Subjects Effects

Measure:MEASURE_1
Transformed Variable:Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Intercept	.595	1	.595	123.401	.000
Experiment_Validity	7.470E-5	1	7.470E-5	.015	.901
Error	.704	146	.005		

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