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The Priming Effects of Task Irrelevant Information

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ABSTRACT

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Much research has shown that information outside of awareness can be processed to some degree. Here we used overlapping pictures and words presented in a RSVP paradigm to examine the effect of semantic congruency in an unattended dimension on performance in an attended dimension. We hypothesized that if unattended information is processed, then by manipulating the congruency of the dimensions we may see facilitory or inhibitory effects on subject's responses to attended items. We found that when an unattended congruent word preceded a picture target by a lag of 2 items or 4 items, responses to that target picture were speeded compared to when the word was unrelated to the target. This finding suggests that the unattended information is being processed to the level at which it can influence behavior and that this processing lasts for an extended duration after the item is presented.

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Introduction

A long-standing debate in the literature has surrounded whether or not information that we are not aware of is still processed, and if so, to what extent this information is processed. In the early days of cognitive psychology the issue concerned whether information we were told to ignore would still be processed; this issue framed the early vs. late selection debate. Using the dichotic listening paradigm, researchers proposed various models of selection and outlined the various features that may be processed outside of awareness. Over the last few decades, research both on patient populations and normal subjects has shown that information we are not consciously aware of is still processed sufficiently to prime motor responses, prime semantic associations, direct attention, and shows simple form processing. The purpose of the present study was to examine the processing capabilities of the unattended channel. Our attempt was to investigate the extent to which items are processed without attention and examine any similarities between processing that occurs on attended and unattended items. The approach was twofold. First, we examined the extent to which unattended items which are congruent with attended influenced responses to items in the attended dimension, and second, we examined the extent to which phenomenon that occur when items are attended also occur when they are not attended, namely repetition redundancy and/or repetition blindness. The purpose of these two aspects of the experiment was to allow us to approach the question regarding the processing capacities of the unattended system from converging directions in order to advance to a better understanding of the operations of this system.

Much research has been done on the effects that attention has on the selection and processing of information. Attention has been shown to select information based on features and locations, both at the top-down (predefined) and bottom-up (salience-driven) levels. Attention is able to selectively process certain features, at the expense of others (Treisman, 1982; Yantis & Egeth, 1999). In manipulating spatial attention, much work has shown that the focus of attention can be distributed across the visual field or narrowed to one location or hemifield (see Pashler, 1998 for a review). Attention has also been shown to enhance processing of information by enhancing spatial resolution and speeding up the rate of information processing (Yeshurun & Carrasco, 1998; Carrasco & McElree, 2001). However, there is often some processing occurring on distracter or unattended items as well. Using the dichotic listening and shadowing techniques, researchers have shown that subjects can report information presented in the unattended channel (Cherry, 1953; Moray, 1959; Treisman, 1960), most of the time without realizing that they were doing so.

In an attempt to resolve whether incoming information is selected for further attentional processing early in the processing stream (early selection) or whether information is processed in full and then selected for access to awareness (late selection), Lavie (1995) conducted a series of experiments that outlined the conditions that may produce either early or late selection of information. Lavie (1995) showed that perceptual load can influence featural processing and attentional selection of information. In her first experiment, she presented subjects with either one or six letters for which they were to report the presence or absence of a target letter, along with the presentation of a surrounding irrelevant distracter. The distracter could be either congruent with the target

or incongruent. Previous work by Eriksen & Eriken (1979) has shown that the presence of incongruent distracters can interfere with and slow down responses to the target. Lavie found that subjects were only affected by the irrelevant distracters in the low load condition (center display of one item), but not in the high load condition. She also found the same result with additional attentional manipulations, including processing color vs. a featural conjunction (Experiment 2), and detection vs. identification of location and size (Experiment 3). This finding can be explained by the fact that the low load condition was not attentionally taxing and possibly there were additional resources remaining to process the irrelevant distracters. However, in the high load condition, all the attentional resources needed to be allocated to searching for the target, and there were none left over to process the irrelevant distracters, thus preventing them from interfering with performance.

There are many examples of processing occurring without awareness with the unattended or unconscious items still affecting performance. Following a lesion to V1, some patients report no phenomenological awareness of stimuli presented in their blind visual fields. However, forced choice and localization paradigms have revealed that these patients can nonetheless discriminate basic features such as orientation, motion, and shape in their blind fields at levels above chance. This phenomenon, known as "blindsight", was first labeled as such by Weiskrantz et al. in 1974. Kolb and Braun (1995) have examined blindsight in normal subjects by presenting two complimentary patterns to each eye, such that a target appearing in one of four visual quadrants that was clearly visible when presented alone, was rendered invisible to the subject via binocular rivalry. They found that although subjects were not able to perceive the target

consciously, they were still able to guess at levels above chance as to the quadrant in which it appeared. It should be noted, however, that Morgan, Mason, and Solomon (1997) attempted to replicate the Kolb and Braun study, using both monocular and binocular presentations of the complimentary patterns, and found that subjects were able to detect the target in both conditions. Therefore, the ability to produce blindsight in normal subjects remains to be resolved.

Another example of processing without awareness involves patients who have damage to the medial temporal region and show a memory disorder known as amnesia, in which they cannot consciously recollect events or items probed on explicit recall test, but show intact implicit memory for these items when probed indirectly using priming tasks (Schacter, 1992). Cavaco, Anderson, Allen, Castro-Caldas, and Damasio (2004) have shown that amnesic patients show intact motor/procedural learning for a variety of skills they do not consciously remember learning. Blindsight and amnesic studies have provided nice examples of the existence of processing without awareness.

The typical assessment of processing without awareness is twofold (Schacter, 1992). First, there is a direct measure of conscious knowledge. For example, in the amnesic studies, patients are asked to explicitly recall a list of words they studied. The second measure of processing without awareness is an indirect measure. This is a way of assessing whether there was processing occurring outside the subject's awareness by examining performance on some other task. This typically includes priming tasks, which indirectly tap the patient's knowledge of a prior presentation. Other indirect measures include performance on tasks that subjects are not aware they are accurately completing, such as performance on motor learning tasks and guessing at stimuli they are not aware

of (as in blindsight). Together, the direct measure reveals the level of conscious awareness and the indirect measure reveals the level of unconscious processing, or processing outside of awareness.

A typical methodology used in normal subjects to render stimuli invisible (or to prevent stimuli from entering awareness) is visual masking. Visual masking occurs when visibility of a target item is reduced or abolished due to the presentation of a trailing mask. Studies using visual masking fall into two categories: those that use masking to prevent visibility of an item, and those that investigate the mechanisms of masking itself. Studies examining the mechanisms of masking have revealed several different types of visual masking, including object substitution masking, pattern masking, and metacontrast masking. Object substitution is a newly-discovered form of masking which occurs when a target and a four dot perimeter mask onset simultaneously, but the mask offsets at a delay following the target. The target is rendered invisible because the prolonged image of the mask disrupts and overrides the ongoing neural response to the previously displayed target (Enns & DiLollo, 1997; Enns, 2004). Pattern masking occurs when the mask is a random array of lines, dots, or other elementary features and appears at some delay, in the same spatial location as the target (i.e., is superimposed on the target). In this case visibility of the target is reduced because the visual system is not able to separate the target and the mask temporally, and thus the percept of the target is degraded due to the "noise" induced by the mask (Enns & DiLollo, 2000). The target detection by SOA pattern masking function shows maximal masking at the 0 SOA (simultaneous presentation), with increasing detection as SOA increases. Metacontrast masking occurs when a spatially adjacent (non-overlapping) mask prevents awareness of a preceding

target when it follows the target at an optimal stimulus onset asynchrony (SOA). In contrast to the pattern masking function, the metacontrast masking function is "U" shaped, with maximal target detection at the 0 SOA, followed by optimal masking at an SOA between 40 – 60 ms, and then an increase in detection with increasing SOA until maximal performance is reached again at an SOA of about 200 – 300 ms (Breitmeyer, 1984). It is thought that the onset of the mask, which is carried in a fast transient neural signal inhibits or overrides the ongoing sustained neural response to the prior target. The targets signal is now degraded, thus decreasing its visibility (Breitmeyer, 1984). Macknik and Livingstone (1998) found that the initial onset response and after-discharge of a cell in V1 are important for visual awareness, and that forward masking (mask presented prior to the target) suppresses the initial onset response, while backward masking (mask presented after the target) suppresses the after-discharge, thus preventing awareness.

Research has shown that although the mask prevents awareness of the target stimulus, the target is still able to prime responses to the mask. Klotz and Neumann (1999) used metacontrast stimuli in which the first stimulus could be either congruent (the same shape), incongruent (a different shape) or neutral with respect to the following target (also acting as a mask). The subject's task was to identify the location (right, left) of a predetermined target shape. They found that when the prime (first stimulus) was congruent with the target (mask), responses were faster, than when responses were incongruent, even though subjects were unable to identify the prime (their performance was not better than chance). Vorberg, Mattler, Heinecke, Schmidt, and Schwarzbach (2003) found that subjects were faster to respond to the direction of an arrow mask when the preceding target was congruent (pointed the same direction) than when it was

incongruent with the mask. This indicates that there is response priming to items presented in the focus of attention, but in the absence of awareness.

Those studies that use visual masking to prevent visibility of a stimulus have predominantly examined semantic priming. The first question in examining the capabilities of the unattended channel is to ask the extent to which information in an unattended channel influences responses to information in the attended channel. In the case of semantic priming, researchers use masked priming tasks as well as stem completion tasks and lexical decision tasks to examine the extent of processing of an item that was not consciously perceived (or remembered, as in the case of amnesia). In a stem completion task, subjects are presented with a list of words to remember and then in a later test phase are given the first few letters of a word and asked to complete the word. Priming is said to occur when subjects are faster and more accurate at completing stems for items that were in the list they learned than for items that were not in the list. In a lexical decision task, a letter string may be presented with another letter string and the subject is to decide if both are words (Meyer & Schvaneveldt, 1971), or more commonly, a word is presented, masked, and the subject makes a word/non-word decision to a following letter string (Neely, 1991). Priming is shown when subjects are faster and more accurate when the two letter strings are the same or related words. Also, the magnitude of priming has been shown to be larger when the items are from the same semantic category (e.g., bread and butter), than when they are from unrelated categories (e.g., doctor and butter; Neely, 1991). This priming occurs independently of conscious recollection or perception of the items. For example, the depth of encoding is known to affect the ability to consciously recall studied items, however, it does not affect the

magnitude of priming. Priming is the same regardless of the depth of encoding. Priming also occurs regardless of whether the item was ever perceived, that is, priming still occurs when items are masked and never enter conscious awareness (Marcel, 1983). Marcel (1983) showed that the magnitude of the priming was the same regardless of whether the item was perceived or not, indicating conscious awareness is not necessary for performance and no gain is accrued by it.

Another methodology used to assess the effects of semantic congruency on performance is the picture-word interference task. This task involves presenting subjects with a picture and word superimposed, and asking the subject to name the picture. By varying the semantic congruency of the picture and the word, researchers have shown that semantically related items produce a *slowing* of picture naming. This effect is thought to have a lexical locus, although this is still controversial (Damian & Bowers, 2003; Damian & Martin, 1998). Rees, Russell, Frith, and Driver (1999) used this task to examine a different question, namely the effect of the unattended item and its extent of processing. They presented subjects with the typical Snodgrass and Vanderwart (1980) pictures used in most picture-word interference tasks with a word or a non-word superimposed and asked subject to either attend to the picture or word dimension in a rapid serial visual processing stream (RSVP) in order to detect a repetition. This allowed them to asses whether words and non-words are processed differently in the brain when they are unattended (as they are when attended) and thus draw conclusions about the extent of unattended processing. Using fMRI, they found that when subjects were not attending to the words that the difference between word and non-word activation was eliminated thus leading them to conclude that without attention word reading/processing

is abolished (Rees, et al. 1999). They claim that it was the taxing demands of the picture task that prevented subjects from being able to distinguish between the non-word letter strings and the words. However, from the point of view of a late selectionist, they are inconclusive regarding whether the unattended words were processed. It may be the case that the unattended information was processed only superficially and for a short period of time before full resources were devoted to the processing of the attended information. Due to the slow time course of the hemodynamic response measured by fMRI and the limitations of the statistical power using this method, this possibility cannot be ruled out.

Damian and Bowers (2003) have also examined the effect of congruency on performance in a picture-picture interference task. The procedure was the same as in the picture-word task but now the congruency of a superimposed picture-in-picture was manipulated. They found that when the two dimensions (the larger picture and the smaller, superimposed picture) were presented at the same time (0 ms SOA, that which produces the most picture-word interference) there was a significant congruency effect on picture naming latencies. This is an interesting result showing that superimposed words produce interference in picture naming, but superimposed pictures produce facilitation in the same naming task.

The second question in examining the processing capabilities of the unattended channel is to ask the extents to which phenomena that occur when information is attended will also occur when it is not. There are several reasons to think that unattended information may be processed similarly to attended information. First, semantic priming studies show that words that do not enter consciousness are still processed to the level of semantics and can influence later performance, as if they were in fact visible. However

the level of processing of these stimuli is different from those that are attended (e.g., there is no awareness or memory for them) and therefore, such phenomena present with attention may not be present without it. The picture-word paradigm and the task of detecting a repetition provides a nice opportunity for examining whether a repetition in the unattended dimension can produce any type of facilitation or interference, namely repetition redundancy or repetition blindness, which are phenomenon that occur in the attended dimension (i.e., the dimension typically studied).

Repetition redundancy occurs when subjects are faster to detect a target when it occurs in more than one stream of information they are attending to and filtering (Miller & Reynolds, 2003). For example, if a subject is monitoring for a visual 'X' and a tone, responses will be faster if they occur simultaneously than if they occur at different times. This effect occurs within and across modalities and is taken as evidence for parallel processing of the targets (Mordkoff & Yantis, 1991). There are three common theories for why this redundancy speeding occurs. First, Raab (1962) predicted a race model in which the response is the average time of all the response channels and thus when there are multiple targets in multiple channels that mean response is faster than any alone. This model has been refuted by some (e.g., Miller, 1982) and a new coactivation model proposed. In the coactivation model, each target's activation sums with the others to produce a faster response than any target alone (Miller, 1982). The race model and coactivation model have been expanded upon by Mordkoff and Yantis (1991) in an interactive race model which encompasses crosstalk between the channels prior to any response in order to account for top down effects.

Repetition blindness (RB) occurs when subjects are less accurate in reporting two identical items presented in RSVP format than two different items. Unlike with the redundancy effect, the items are usually separated in time. This effect has been shown with picture stimuli, colors, and letters, but is most commonly investigated with a series of words making up a sentence (Park & Kanwisher, 1994). RB occurs at presentation rates of 143 ms per item or faster (Kanwisher, 1987), seems to be present only in vision (Kanwisher & Potter, 1989), and the degree of similarity between the two items for producing the blindness remains controversial (Park & Kanwisher, 1994). It has also been shown to occur when subjects are searching a spatial array (Mozer, 1989) and not just with RSVP. The predominant theory for why this occurs posits that information first undergoes a recognition process which involves matching the visual input to a mental representation (type), followed by an individualization process whereby there is binding of the representation to an episodic memory for the event (token; Kanwisher, 1987). Under this token individualization hypothesis the repeated item undergoes recognition but the second occurrence never gets individualized and thus there is no episodic memory for the second event. This explains why the repeated word is rarely reported (Kanwisher, 1987).

In conclusion, the current studies assessed the extent to which unattended information is processed and can influence responses, and attempted to overcome the shortcomings of the Rees, et al. (1999) experiment by examining the influence of the unattended information on a behavioral (motor) response to the attended information. If unattended information is processed at all, then by manipulating the congruency of the dimensions we may be able to see any effects this may have on the subject's responses to

the attended items. We employed overlapping picture-word and picture-picture stimuli presented in a RSVP stream and subjects were instructed to attend to only one of the dimensions with the task of detecting a repetition. We manipulated the congruency of the items in the two dimensions to examine whether that would lead to priming/interference and varied the lag of the congruency to examine the time course of the effects. We also examined any differences between the time course of the congruency effect for picture-picture and picture-word stimuli. If it is true that unattended information is not processed at all, then its congruency with the attended channel should neither speed up nor slow down responses to the attended targets. However, if unattended information is processed, then we should see either a speeding or slowing (priming or interference) of responses to the target in the attended dimension. Although it is not of great interest whether response priming or interference emerges, both effects are possible. The picture-word interference task has shown that congruency produces interference, or a slowing of picture naming. However, this task is different from the one employed here, in that in the picture-word task stimuli are presented one at a time for a long duration (~2 seconds) and subjects are required to make a verbal response. In contrast, in semantic priming tasks congruency has been shown to facilitate responses, and given that priming studies more closely mirror the current study in presentation times and response options, it may be more likely that facilitation/priming will ensue here. We also varied the lag between the congruent item in the unattended and the attended dimension, which allowed us to assess whether the largest priming/interference effect occurs when the items are presented concurrently or when they are separated by 167 ms, or 200 ms, etc. This paradigm also allows us to examine whether phenomenon which occur with attended information also occur with

unattended information, namely repetition redundancy and repetition blindness. We examined whether repetitions in the unattended dimension would produce repetition redundancy or repetition blindness and thus modulate any priming/interference seen during conditions without such repetitions. If repetition redundancy occurs in the unattended dimension then we should find a more substantial speeding of responses to attended targets when the first repeated item (R1) and the second repeated item (R2) in the attended dimension and the unattended dimension are all congruent vs. when just R1 in the unattended and R1 and R2 in the attended dimension are congruent. Repetition redundancy is also possible when the item in the unattended dimension is congruent with the second repeat item in the attended dimension (R2 or the target), although it may not be as substantial an effect as in the first case. If repetition blindness occurs in the unattended dimension then we should expect to find no difference between the conditions in which the R1 in the unattended dimension is congruent with R1 and R2 in the attended dimension and the condition in which R1 and R2 unattended is congruent with R1 and R2 attended.

Method

Experiment 1: Picture/Word

Participants. Twenty-two subjects were recruited from the Rice University Psychology Department research pool and received course credit for participation, or were recruited from the Rice University general population and paid ($8/hour) for their participation. Five subjects were eliminated from the analyses because their low response rates led to conditions with no responses (i.e., empty cells). All subjects were native English speakers, had normal or corrected to normal vision and participated only after providing informed consent.

Stimuli and Apparatus and Procedure. All stimuli were presented on a 40 cm horizontal by 30 cm vertical CRT monitor with a refresh rate of 60 Hz, powered by a Dell PC computer. The subjects viewed the screen from a distance of 57cm, such that one cm of the screen corresponded to one degree of visual angle. The stimuli appeared in the center of the screen following the presentation of a fixation cross at the onset of the trial. Each of 20 images appeared for either 167 or 200 ms depending on the trial type. These durations were chosen based on pilot data showing that shorter durations made the task too difficult for subjects and longer durations allowed for the processing of both dimensions. The stimuli were presented in a rapid serial visual presentation format (RSVP) with no interstimulus interval between items. The stimuli were Snodgrass and Vanderwart (1980) pictures with a word superimposed (see Figure 1).

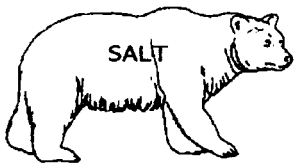


Figure 1. This is an example of the picture-word stimuli used in Experiments 1 and 2.

The words used were the names of the pictures. See Appendix A for a list of the pictures and words. All words were between 3 and 8 letters in length. The pictures were black line drawings presented on a white background and the words were presented in Lucida Console 14 point green font. The green font color was used in order to distinguish the lines of the words from the lines in the pictures. This font was chosen because the upper and lower case versions were the same size. The pictures ranged in size depending on their form, from 13.9°L x 0.6°W x 0.7°H for a needle to 20.2°L x 20.7°W x 9.8°H for a house[1]. The words ranged in size from 2°W x 0.8°H for a three letter word and 5.8°W x 0.8°H for an eight letter word. The pictures were rotated -30 and +30 degrees and the superimposed word either appeared in upper or lower case randomly in order to distinguish between successive items and prevent spatial and temporal summation of

[1] These were 2D images with width representing the east-west measurement, height representing the north-south measurement of the object, and length representing the length of the object irrespective of the orientation. For example, a needle is only 0.6°W at the widest point, but it has a long length of 13.9°. This is not the height or width because it changes with the rotation.

information. For the repeated items, the repeated picture always appeared in a different rotation from the first presentation of the repeated picture and the repeated word appeared in a different case, to insure that they were distinguishable. The words and their corresponding pictures were divided into two groups, such that one of the groups of items would make up the attended group and the other would be the unattended group. The placement of the groups was fully counterbalanced with dimension attended. The subject either attended to the picture or the word dimension in a given block (counterbalanced across subjects) in order to detect the presence of a repetition in that dimension. The repetition was presented randomly as the 9-15 item, as previous work has shown that repetitions presented early in a stream are more readily detected (Treisman, Squire, & Green, 1974). As soon as the repetition was detected subjects were to make a speeded response on the keypad. Reaction times were measured from the onset of the repeated picture. The items continued to be presented until 20 had been shown. Therefore, the subjects did not know if they were correct in detecting the repeat. The trial ended with a fixation cross. Each new trial was initiated by the subject, thus allowing for breaks as needed.

Design. There were four different conditions presented in a within subjects design (see Figure 2). First, in the non-word condition, the picture stimuli were superimposed with non-words, and the subject's task was to either attend picture or attend word in order to detect the repetition, as in every other condition. The use of non-words allowed us to assess the effects of attending to a dimension without the possibility of semantic interference or priming. All the non-words were selected from the Rastle, Harrington, and Coltheart (2002) non-word database (See Appendix B). In the congruent R2 condition,

the item in the unattended dimension was congruent with the second presentation of the repeat item in the attended dimension (R2 or the target). This allowed us to asses the effects that congruency had when it was presented at the same time as the target item. This is the condition that had the highest probability of producing repetition redundancy effects. In the congruent R1 condition, the item in the unattended dimension was congruent with the first repetition of the item in the attended dimension (R1). This allowed us to asses the effects that congruency had when it was presented just prior to the target and was the same as the first repetition. If semantic priming takes some time to build then we would expect that this condition would produce more priming than the last condition in which the unattended congruent item was presented at the same time as the target. In the congruent/congruent condition, both the item in the unattended dimension presented with R1 and the item presented with R2 were congruent with the attended dimension. In this condition we may see maximal priming due to the fact that both repeated items possessed congruency in the other dimension, and the priming may be the sum of what we may see in the congruent R1 and congruent R2 conditions. Alternatively, if it is possible for repetition blindness to occur in the unattended dimension then performance in this condition should not differ from that in the congruent R1 condition.

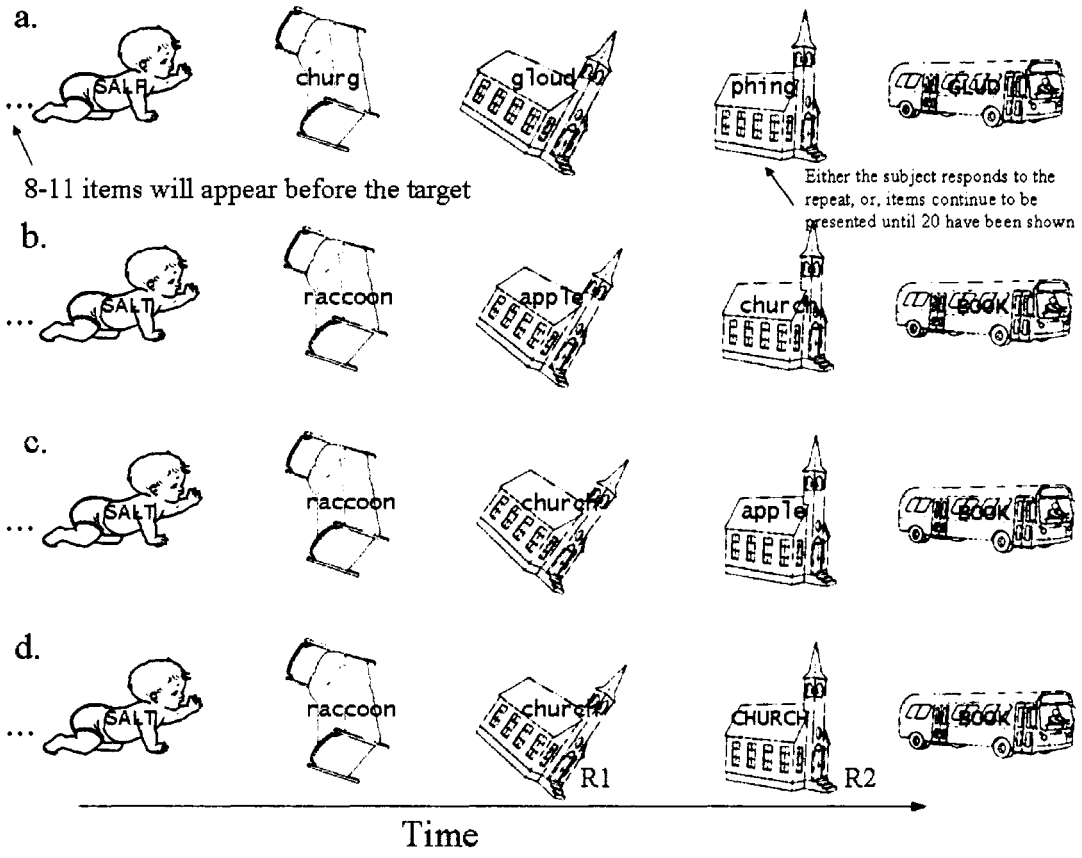


Figure 2. This is a schematic showing the sequence of events in Experiment 1. In each of the four conditions (a.-d.) the subject was instructed to attend to either the picture or word dimension with the task of detecting a repeat. The attend picture task is shown. The target item was presented as the 9-12 item in the RSVP stream. If the subject detects the repeat they are to respond with a button press as quickly as possible. a. depicts condition 1, in which the pictures were superimposed with non-words (nw). b. depicts condition 2, in which the item in the unattended dimension was congruent with the second repeat item (cR2) in the attended condition. c. depicts condition 3, in which the item in the unattended dimension was congruent with the first repetition of the item in the attended dimension (cR1). d. depicts condition 4, in which both the item in the unattended

dimension presented with R1 and the item presented with R2 was congruent with the attended dimension (cc).

One problem in conducting these studies is determining the extent to which subjects are attending to the dimension assigned and not sampling from the unattended dimension. We employed two methods to attempt to control for this problem. First, pilot studies were run in which subjects were presented with the picture-word stimuli at durations of 100, 117, 133, 167, 183, 200, and 250 ms each (i.e., one trial of 20 items each presented at 100 ms, etc.) and asked to detect the repeated item while attending to either the picture or the word dimension. This allowed us to assess the duration at which subjects are not able to perform the task to a criterion of 30% response (repeat detection) in the attend word condition and a 50% response in the attend picture condition. However, we also were able to eliminate long durations in which subjects could process both dimensions accurately (they could switch between dimensions as a result of the long presentation time). The second method we employed to be relatively certain that the subjects were not processing both dimensions on each trial was a manipulation of the number of experimental trials. This study contained only 20% experimental trials and 80% filler trials. On the filler trials all the items in the unattended dimension were from a different semantic group than the items in the attended dimension (See Appendix A). Therefore, accessing the unattended dimension would have been detrimental to task performance and there would have been no motive for the subjects to do so (Damian & Bowers, 2003).

There were 14 experimental trials for each condition (7 trials at each duration of 167 and 200 ms) and four conditions for a total of 56 experimental trials. There were also 14 trials without a repeat in order to asses subjects false alarm rate. With 20% experimental trials and 80% filler trials, there were also 210 filler trials. The total number of trials for the experiment is 280. The computer randomly presented all trials. The subject completed one version of the experiment in which they attended to the picture dimension and one in which they attended to the word dimension, with 280 trials in each, for a total of 560 trials per session. Subjects were also given 12 practice trials at the beginning of each experiment to acquaint the subject with the task, totaling 24 practice trials per session. These practice trials included no experimental manipulation and were excluded from any analyses. Subjects took between 55 minutes and 1.5 hours to complete the session.

Experiment 2: Picture/Word Lag

Participants. Seventeen subjects were recruited from the Rice University Psychology Department research pool and received course credit for their participation. The data for one subject was eliminated due to computer problems. All subjects were native English speakers, had normal or corrected to normal vision and participated only after providing informed consent.

Stimuli and Apparatus and Procedure. The experimental setup was the same as in Experiment 1. This experiment differed in that there was a variable lag of 2 to 5 items between the presentation of the congruent item in the unattended dimension and the repeated item (R2) in the attended dimension (see Figure 3). This allowed us to assess the

maximal duration of any priming/interference effects and map out the time course of this effect as a function of lag. There was no non-word condition in this experiment.

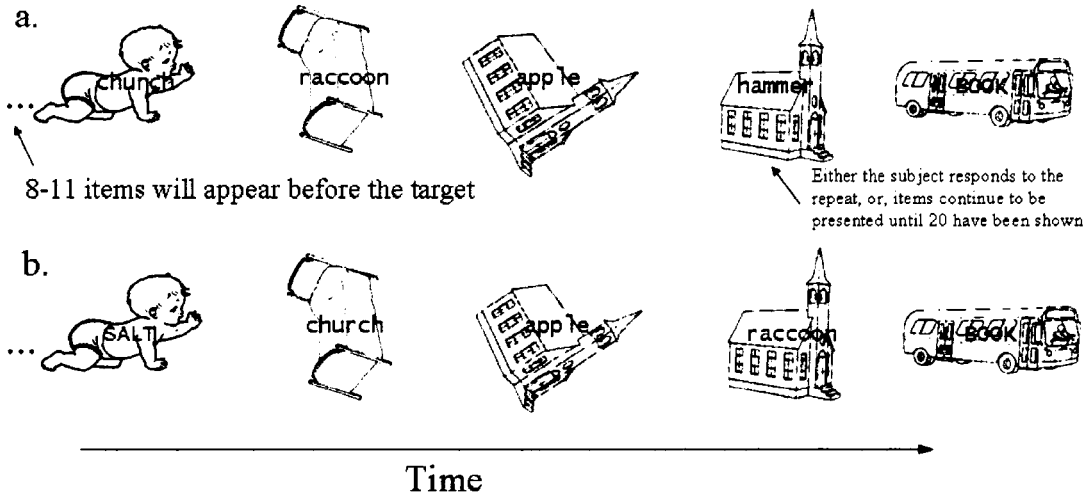


Figure 3. This is a schematic showing the variable lag between the congruent item in the unattended and attended dimension in Experiment 2. The attend picture task is shown. a. shows a lag of 3 items and b. shows a lag of 2 items. The lag varied randomly between 2-5 items.

Experiment 3: Picture/Picture

Participants. Seventeen subjects were recruited from the Rice University Psychology Department research pool and received course credit for their participation. The data from one subject was eliminated from the analyses because his/her low response

rates led to conditions with no responses (i.e., empty cells). All subjects were native English speakers, had normal or corrected to normal vision and participated only after providing informed consent.

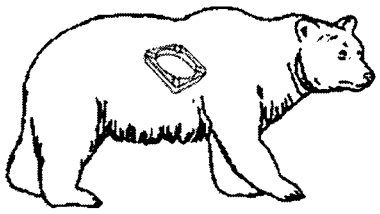


Figure 4. This is an example of the picture-picture stimuli used in Experiments 3 and 4.

Stimuli and Apparatus and Procedure. The experimental setup was the same as in Experiment 1. This experiment differed in that instead of using pictures with superimposed words, the stimuli were pictures with smaller scale pictures superimposed (see Figure 4). All images were from the Snodgrass and Vanderwart (1980) picture set. The same pictures were used as in Experiment 1 (See Appendix A). The large pictures were exactly the same as those used in the picture/word experiment and varied in size depending on their form, from 13.9°L x 0.6°W x 0.7°H for a needle to 20.2°L x 20.7°W x 9.8°H for a house. The small pictures were created by reducing the large pictures to 25%

of their original size. Therefore the small pictures still varied in size depending on their form, from 3.5°L x 0.2°W x 0.2°H for a needle to 5.1°L x 5.2°W x 2.5°H for a house. If word reading is automatic and occurs whether attended or not, then the use of picture stimuli may be a better assessment of the degree to which processing occurs in the unattended dimension. In other words, we may find that when subjects are to attend picture and ignore the words in Experiment 1, the words may still produce priming or interference because their processing is automatic. However, picture processing does not follow the same processing steps as word reading/naming and thus the same assumption can not be made as with words. Damian and Bowers (2003) have also shown using a picture-picture task that semantic congruency produces a facilitation of naming latencies, which is counter to the interference produced in the picture-word task. Also, it may be the case that the time course of any priming/interference effects is different and we can map out the effect with picture-picture stimuli in the same manner as with the picture-word stimuli. That said, the conditions in this experiment were the same as in Experiment 1, except that no non-word condition was used since the stimuli in this experiment were all pictures, and we used three presentation durations: 133, 167, and 200 ms. The addition of the 133 duration condition increased the number of trials to 315. Subjects participated in one version of the experiment in which they attended to the small pictures and one in which they attended to the large pictures in order to detect the repeated item (counterbalanced across subjects). Subjects completed both versions in 1 to 1.5 hours.

Experiment 4: Picture/Picture Lag

Participants. Sixteen subjects were recruited from the Rice University Psychology Department research pool and received course credit for their participation.

The data from one subject was eliminated from the analyses because his/her low response rates led to conditions with no responses (i.e., empty cells). All subjects were native English speakers, had normal or corrected to normal vision and participate only after providing informed consent.

Stimuli and Apparatus and Procedure. The experimental setup was the same as in Experiment 3. However, this experiment varied the lag (2-5 items) between the congruency of the item in the unattended dimension and the repetition (R2 or the target) in the attended dimension. This allowed us to assess the maximal duration of any priming/interference effects and map out the time course of this effect as a function of lag. This experiment only used presentation durations of 133 and 167 ms, as the 200 ms condition in Experiment 3 proved to be too long for the processing of picture stimuli. There were 280 trials per experiment.

Results

Experiment 1: Picture/Word

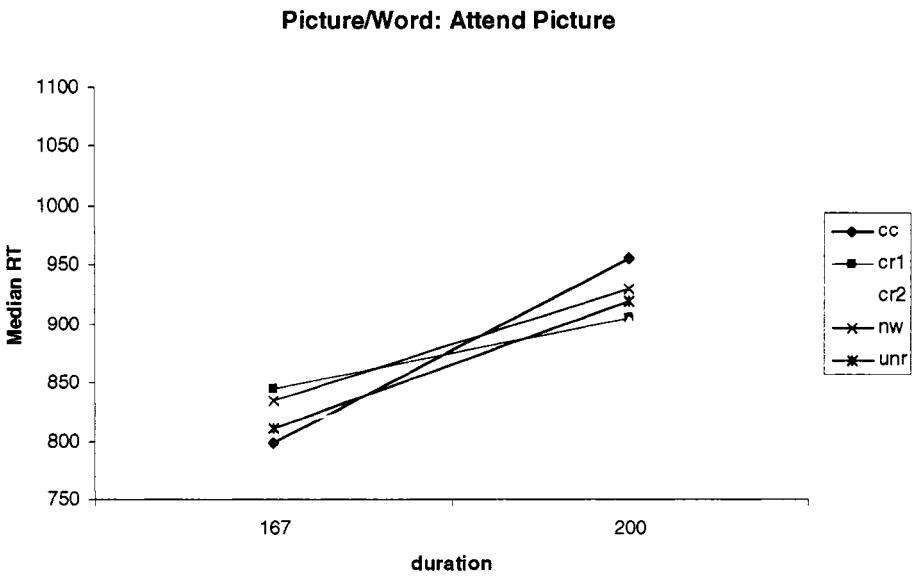
Twenty-two subjects completed two versions of this experiment, one in which they attended to the picture dimension and one in which they attended to the word dimension (counterbalanced across subjects). This resulted in two data files for each subject. For each data file, all trials were inspected in order to exclude trials in which the computer randomly displayed the repeated item either before the first presentation of the repeated item or after the target (i.e., the target was presented three times in a row), or to exclude trials in which any other item in the stream was presented twice in a row (i.e., there were two repeat sets in that trial). This led to the exclusion of 4.2% of trials in this experiment. Trials in which the subject failed to detect the repeated item were scored as a

"no response" trial and trials in which the subject responded before the repeat was presented or within 500 ms of the onset of the repeated item (the target) were scored as an "anticipation error" and the reaction time was excluded. Anticipation errors occurred when the subject incorrectly thought another item in the stream had repeated and responded before the repeated target set was presented. This 500 ms exclusion criterion was based on in part on work on lexical decision. In a lexical decision task subjects must decide whether a letter string is a word or non-word. In order to perform this task subject's must determine if a word has a semantic node in their semantic system. If it does, they respond 'word', if not, 'non-word'. Therefore, response timings in a lexical decision task provide us with a nice measure of how long it takes to access the semantic system and make a response based on that (if any) semantic information. Our task is similar in that subject's must decide if two items have the same semantic meaning and, therefore, we can use performance in the lexical decision task to tell us something about the timing of these processes. Babkoff, Faust, and Lavidor (1997) had subjects perform a simple lexical decision task while manipulating the visual field of presentation, and found that it takes an average of 959 ms (SD = 162) for subjects to respond 'word' when the item was presented to the right visual field (which was slightly faster than that to the left visual field: 978 ms). Therefore, the top 5% of responses averaged 554 ms. Since our task differs from the lexical decision task in that subject's must access the semantic information about two items to judge that they are the same or different, our task may be more difficult than the lexical decision task. This may make our responses slower, but nonetheless we trimmed responses that were less than 500 ms. Also in looking at the

distribution of reaction times in this experiment, those falling under 500 ms were rare and clearly below the average response range of 800-1100 ms.

Because there were only 14 trials in each experimental condition, a low response rate or high error rate could produce a condition with no response time (RT) values. This was the case for five subjects, so they were eliminated from all analyses. Following this preprocessing of the data, the median RT for each condition was calculated. We decided to use the median for each condition as a way to control for outliers. We compared the results of trimming for outliers and using the median scores and found that the results were fairly comparable. Therefore, due to the already limited number of trials in the experimental conditions, we thought it best to make use of all the data points. The median RT's were subjected to a within subjects analysis of variance (ANOVA) with attend (picture; word), duration (167; 200 ms), and condition (congruent/congruent; congruent R1; congruent R2; non-word; unrelated) as the variables. The data are depicted graphically in Figure 5.

a.



b.

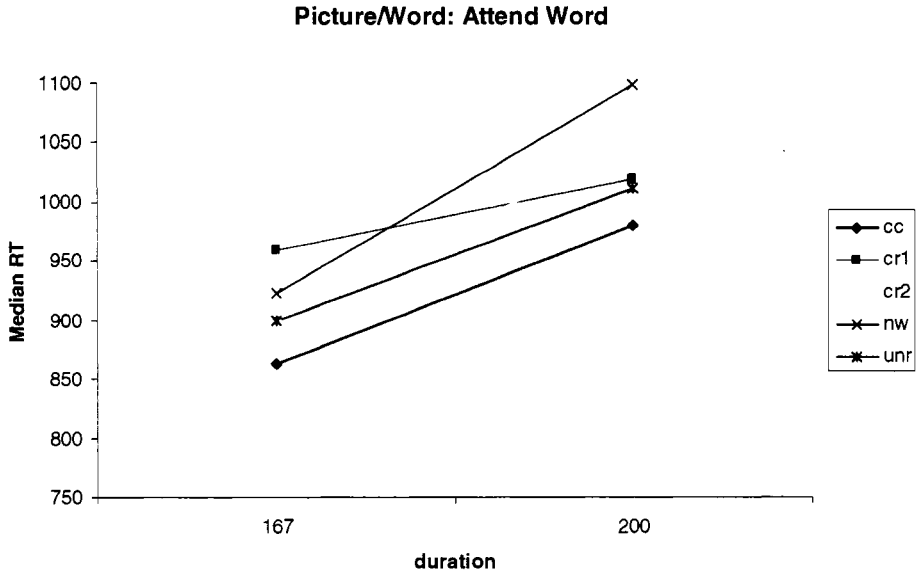


Figure 5. Means of the median reaction times (RT) for each condition in Experiment 1 (Picture/Word Experiment) a. the attend picture task b. the attend word task

The subject's task was to respond as quickly as possible upon detection of a repeated item. The omnibus ANOVA revealed that subjects responded more quickly to the repeated item when attending to the picture dimension (M = 871 ms) than the word dimension (M = 971 ms; $F(1, 16) = 21.43, p < .001$). Subjects were faster to detect the repeated item when the item duration was 167 ms (M = 864 ms) than when it was 200 ms (M = 974 ms; $F(1, 16) = 77.36, p < .001$), and this was true both when subjects were attending to the picture dimension ($F(1, 16) = 88.37, p < .001$) and when they were attending to the word dimension ($F(1, 16) = 20.20, p < .001$). To test our specific predictions regarding differences between the conditions, we performed t-tests between conditional means at each duration. In the attend picture task, at the 200 ms duration the congruent/congruent condition (M = 955 ms) produced significantly slower responses than the congruent R1 condition (M = 905 ms; $t(16) = 2.27, p = .037$) and the congruent R2 condition (M = 902 ms; $t(16) = 2.51, p = .023$). There was a trend toward slower responses in the congruent/congruent condition compared to the unrelated condition (M = 920 ms; $t(16) = 2.28, p = .06$). In the attend word task, at the 167 ms duration the congruent/congruent condition (M = 863 ms) produced significantly faster responses than the congruent R1 condition (M = 959 ms; $t(16) = -2.54, p = .022$). However, when corrected for multiple comparisons using the method of Benjamin and Hochberg (1995), none of these effects remained significant. No other contrasts approached significance.

Response rates were calculated as the number of trials subjects responded that they detected a repeat, divided by the number of possible trials. Response rates were significantly greater when subjects attended to the picture dimension (M = 79.30%) than when they attended to the word dimension (M = 67.07%; $t(16) = 4.976, p < .001$).

Response rates for each condition were analyzed based on the number of "no response" trials per condition (not as a proportion of the total trials). For the experimental conditions, subjects failed to detect the repeated item more often when attending to the word dimension (*M* no response = 2.18) than the picture dimension (*M* no response = 1.52; $F(1, 16) = 10.93$, $p = .004$; comparison of experimental and unrelated conditions was not possible given the difference in number of trials). Subjects failed to detect the repeated item more often when items were presented at a duration of 167 ms (*M* no response = 2.26) than when presented at 200 ms (*M* no response = 1.43; $F(1, 16) = 26.35$, $p < .001$). The same was true for the unrelated trials (*M* no response = 35.47, $F(1, 16) = 21.55$, $p < .001$; *M* no response = 23.35, $F(1, 16) = 29.34$, $p < .001$; respectively). When looking at the response rates in the experimental conditions, a simple effects analysis showed that in the attend picture condition at the 200 ms duration, the congruent/congruent condition (*M* no response = 0.65) had a greater number of responses than any of the other experimental conditions (*M* no response cr1 = 1.47, cr2 = 1.18, nw = 1.41; $F(3, 48) = 2.75$, $p = .05$; comparison with the unrelated condition was not possible given the difference in number of trials). There were no other conditional effects at any duration in the different attentional tasks.

Anticipation error rates were calculated as the number of trials on which subjects made an error (responded too quickly) divided by the total number of possible trials. There were 8.36% anticipation errors in the attend picture task and 10.42% anticipation errors in the attend word task, which did not significantly differ from each other ($t(16) = -1.46$, $p > .05$). Subjects were more likely to make a greater number of anticipation errors when items were presented at a duration of 167 ms than 200ms ($F(1, 16) = 5.86$, $p =$

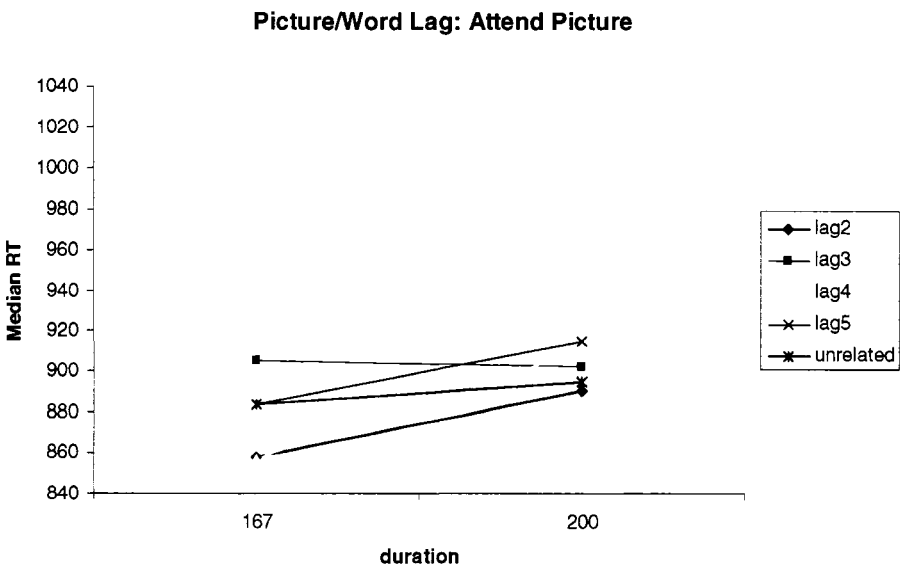
.028), but only for the experimental trials. There was no duration effect on anticipation errors for the unrelated trials ($F(1, 16) = 0.87, p > .05$).

We also calculated how many times subjects reported detecting a repeat when none was presented (responses on the no repeat trials). This was considered a false alarm. The false alarm rate did not differ with the dimension attended ($t(16) = 0.70, p > .05$), as false alarms occurred on average 4 trials out of 14.

Experiment 2: Picture/Word Lag

Seventeen subjects participated in this experiment, although one subject's data was unusable due to computer problems. The data files were preprocessed as in Experiment 1, with one exception. Since the congruent item in the unattended dimension could appear at a variable lag, up to 5, from the target, any trials in which the target item had been randomly presented within 6 items prior to the appearance of the target, and one item after the target were eliminated from analyses. This led to the exclusion of 8.2% of trials in this experiment. Following this preprocessing of the data, the median RT for each condition was calculated and subjected to a within subjects analysis of variance (ANOVA) with attend (picture; word), duration (167; 200 ms), and condition (lag 2; lag 3; lag 4; lag 5; unrelated) as the variables. The data are depicted graphically in Figure 6.

a.



b.

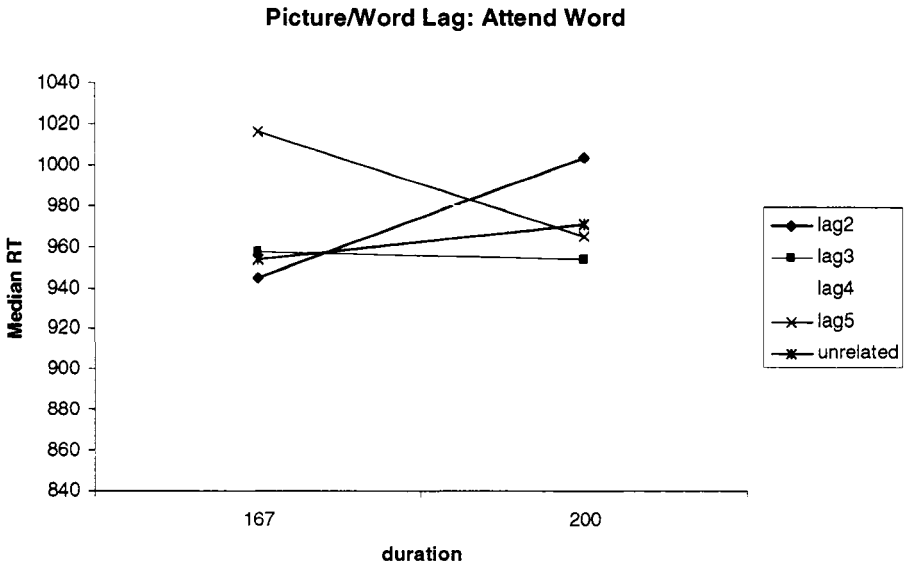


Figure 6. Means of the median reaction times (RT) for each condition in Experiment 2 (Picture/Word Lag Experiment) a. the attend picture task b. the attend word task

The subject's task was to respond as quickly as possible upon detection of a repeated item. The omnibus ANOVA revealed that subjects responded more quickly to the repeated item when attending to the picture dimension (M = 890 ms) than when attending to the word dimension (M = 973 ms; $F(1, 15) = 22.18$, $p < .001$). In contrast to Experiment 1, there was no significant effect of duration ($F(1, 15) = 2.64$, $p > .05$). When testing our specific predictions regarding differences between the conditions, we found that in the attend picture task at the 167 ms duration, responses for lag 2 (M = 858 ms) were significantly faster than lag 3 (M = 906 ms; $t(15) = -2.807$, $p = .013$), responses for lag 4 (M = 857 ms) were faster than lag 3 ($t(15) = 2.78$, $p = .014$), and responses for lag 4 were faster than in the unrelated condition (M = 884 ms; $t(15) = -3.048$, $p = .008$). When corrected for multiple comparisons using the method of Benjamin and Hochberg (1995), all the comparisons remained significant. In the attend word task at the 200 ms duration, responses for lag 2 (M = 1004 ms) were significantly greater than lag 3 (M = 954 ms; $t(15) = 2.143$, $p = .049$), however this effect does not pass the criterion when correcting for multiple comparisons. No other comparisons approached significance.

Response rates were significantly greater when subjects attended to the picture dimension (M = 83.65%) than when they attended to the word dimension (M = 73.82%; $t(15) = 4.134$, $p = .001$). For the experimental conditions, subjects failed to detect the repeated item more often when attending to word dimension (M no response = 1.86) than the picture dimension (M no response = 1.16; $F(1, 15) = 8.75$, $p = .01$; comparison with the unrelated condition was not possible given the difference in number of trials). For the unrelated conditions, subjects failed to detect the repeated item more often when attending to word dimension (M no response = 27.88) than the picture dimension (M no

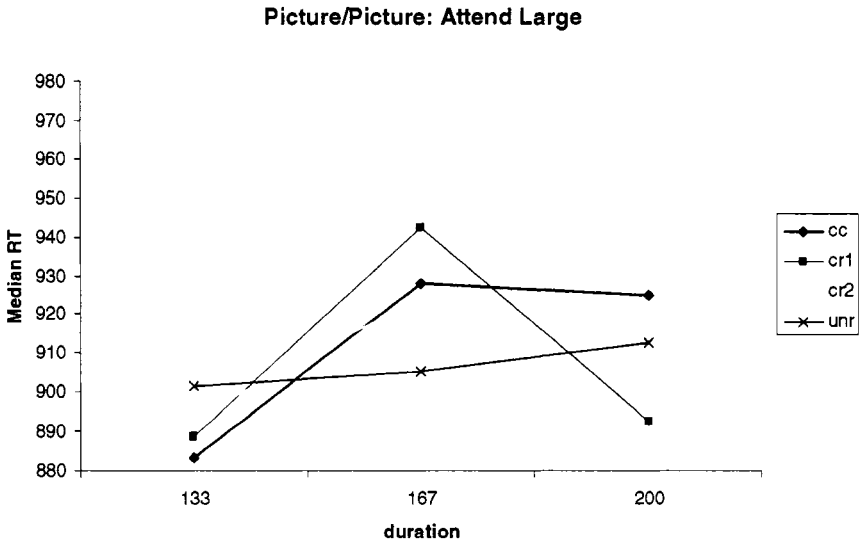
response = 17.47; $F(1, 15) = 17.64, p = .001$). Subjects failed to detect the repeated item in the experimental conditions more often when items were presented at a duration of 167 ms (*M* no response = 1.72) than when presented at 200 ms (*M* no response = 1.30; $F(1, 15) = 17.13, p = .001$). The same was true for the unrelated trials (*M* no response = 26.13, $F(1, 15) = 17.64, p = .001$; *M* no response = 19.22, $F(1, 15) = 38.27, p < .001$; respectively).

There were 5.95% anticipation errors in the attend picture task and 6.69% anticipation errors in the attend word task, which did not significantly differ from each other ($t(15) = -0.62, p > .05$). The anticipation error rates across experimental conditions did not differ from each other ($F(1, 15) = 0.008, p > .05$). The anticipation error rates did not differ across the unrelated conditions either ($F(1, 15) = 0.59, p > .05$). The false alarm rate did not differ with the dimension attended ($t(16) = -0.303, p > .05$), as false alarms occurred on average 4 trials out of 14.

Experiment 3: Picture/Picture

Seventeen subjects participated in this experiment. However one subject was eliminated from the analyses because his/her low response rate led to an empty cell. The data were preprocessed as in Experiment 1. Exclusion of trials in which an item appeared three times in a row or there were two repeated items led to the exclusion of 3.4% of trials in this experiment. The median RT for each condition were calculated and subjected to a within subjects analysis of variance (ANOVA) with attend (large picture; small picture), duration (133; 167; 200 ms), and condition (congruent/congruent; congruent R1; congruent R2; unrelated) as the variables. The data are depicted graphically in Figure 7.

a.



b.

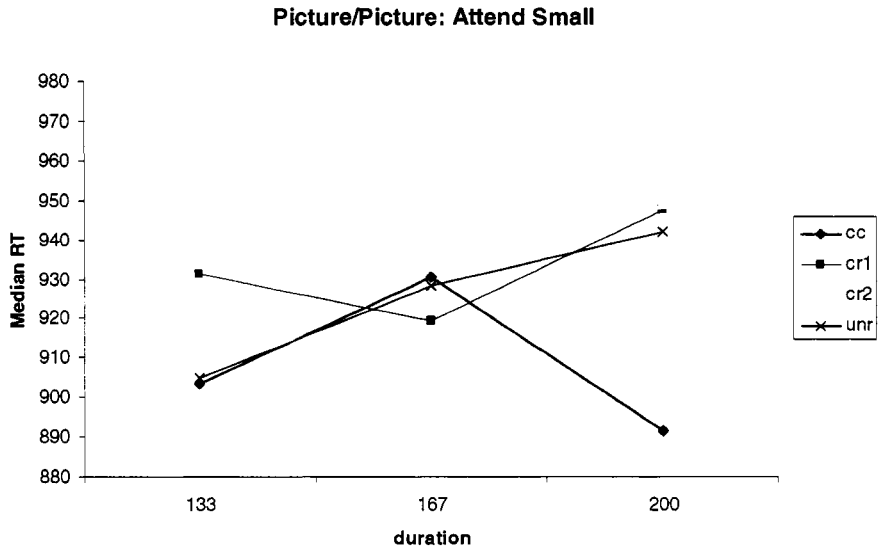


Figure 7. Means of the median reaction times (RT) for each condition in Experiment 3 (Picture/Picture Experiment) a. the attend large picture task b. the attend small picture task

The subject's task was to respond as quickly as possible upon detection of a repeated item. The omnibus ANOVA revealed that there was no performance difference when attending to the large or small pictures ($F(1, 15) = 1.22, p > .05$). There was also no effect of stimulus duration on responses ($F(2, 30) = 1.18, p > .05$). We tested for specific differences between the conditions, and found that when subjects were attending to the small pictures at a duration of 200 ms, they were faster to respond in the congruent/congruent condition ($M = 891$ ms) than in the congruent R2 condition ($M = 949$ ms; $t(15) = -2.47, p = .026$) and the unrelated condition ($M = 942$ ms; $t(15) = -2.68, p = .017$), however these comparisons do not meet the criterion when correcting for multiple comparisons. No other comparisons were significant.

There was no difference between the response rates in the attend large ($M = 88.09\%$) and attend small tasks ($M = 88.54\%$; $t(15) = -0.28, p > .05$). Response rates did vary as a function of presentation duration for the experimental conditions ($F(2, 30) = 4.75, p = .016$) and the unrelated conditions ($F(2, 30) = 5.93, p = .007$), with the greatest number of responses in the 200 ms duration condition (M no response = 0.59 experimental, 7.53 unrelated), followed by the 167 ms (M no response = 0.83 experimental, 9.03 unrelated), and the fewest in the 133 ms condition (M no response = 1.06 experimental, 11.94 unrelated; $F(1, 15) = 12.29, p = .003$; $F(2, 30) = 7.79, p = .014$; for the experimental and unrelated conditions, respectively).

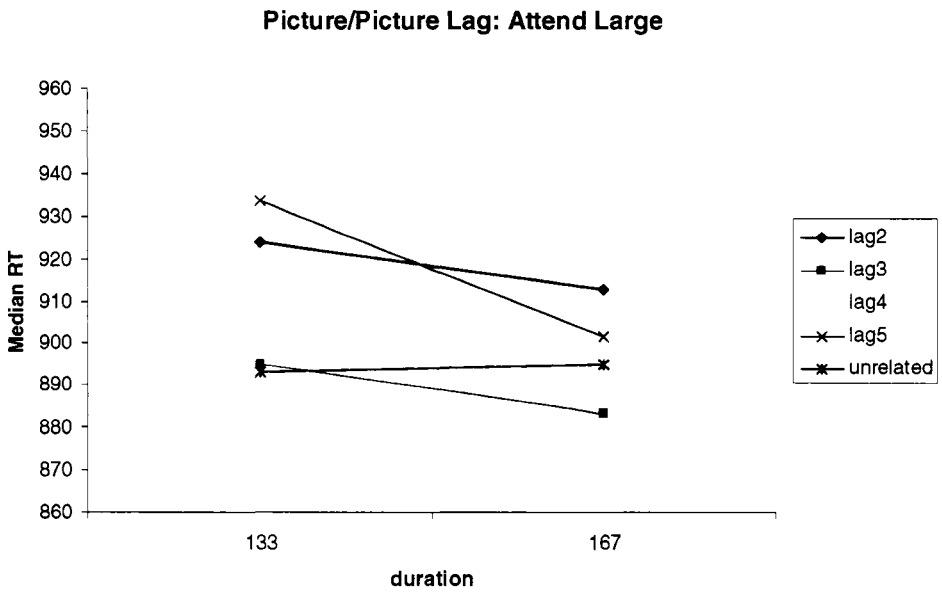
There were 12.69% anticipation errors in the attend large task and 11.53% anticipation errors in the attend small task, which did not significantly differ from each other ($t(15) = 0.74, p > .05$). The anticipation error rates across experimental conditions did not differ from each other ($F(1, 15) = 3.50, p > .05$). The anticipation error rates did

not differ across the unrelated conditions either ($F(1, 15) = 0.86, p > .05$). The false alarm rate did not differ with the dimension attended ($t(15) = 0.42, p > .05$), as false alarms occurred on average 4 trials out of 21.

Experiment 4: Picture/Picture Lag

Sixteen subjects participated in this experiment, however one subject was eliminated from the analyses because his/her low response rate led to an empty cell. The data were preprocessed as in Experiment 2. The exclusion of trials due to three in a row or two repeated items led to the exclusion of 9.2% of trials in this experiment. The median RT for each condition were calculated and subjected to a within subjects analysis of variance (ANOVA) with attend (large picture; small picture), duration (133; 167 ms), and condition (lag 2; lag 3; lag 4; lag 5; unrelated) as the variables. The data are depicted graphically in Figure 8.

a.



b.

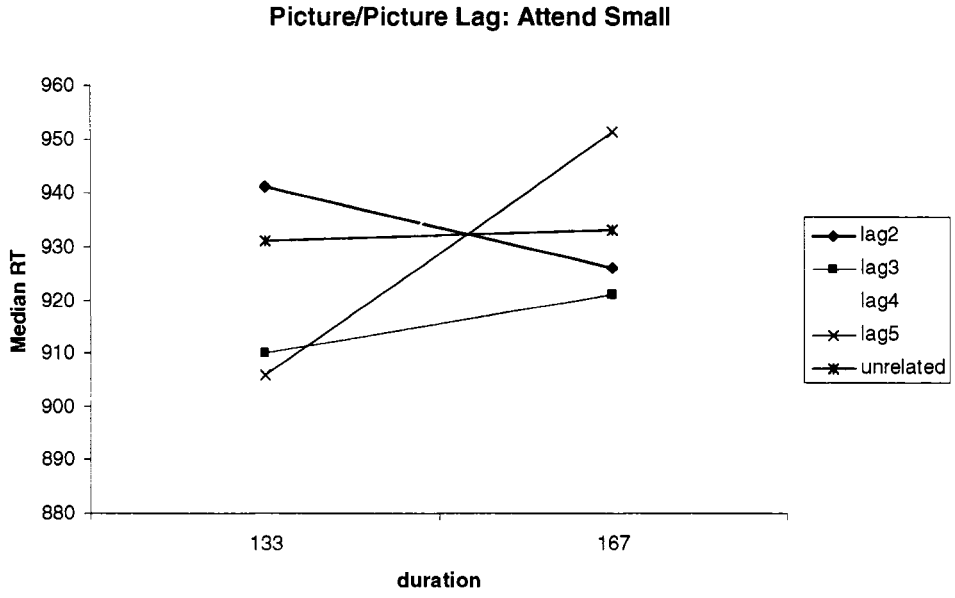


Figure 8. Means of the median reaction times (RT) for each condition in Experiment 4 (Picture/Picture Lag Experiment) a. the attend large picture task b. the attend small picture task

The subject's task was to respond as quickly as possible upon detection of a repeated item. The omnibus ANOVA revealed that there was no performance difference when attending to the large or small pictures ($F(1, 14) = 2.98, p > .05$). There was also no effect of stimulus duration on responses ($F(1, 14) = 0.026, p > .05$). We tested for specific differences between the conditions, but none were found.

There was no difference between the response rates in the attend large (M = 78.37%) and attend small tasks (M = 78.45%; $t(14) = -0.041, p > .05$). Response rates did vary as a function of presentation duration for the experimental conditions ($F(1,14) = 9.93, p = .007$), with the greatest number of responses in the 167 ms duration condition (M no response = 1.33), followed by the 133 ms condition (M no response = 1.68; $F(1, 14) = 9.93, p = .007$). Response rates also varied as a function of presentation duration for the unrelated conditions ($F(1, 14) = 7.18, p = .018$), with the greatest number of responses in the 167 ms duration condition (M no response = 20.17), followed by the 133 ms condition (M no response = 25.80; $F(1, 14) = 7.18, p = .018$). Interestingly, response rates also differed as a function of condition ($F(3, 42) = 4.75, p = .006$), such that the greatest number of responses occurred in the lag 5 condition (M no response = 1.22), followed by the lag 3 condition (M no response = 1.38) and the lag 2 conditions (M no response = 1.55), with the fewest responses in the lag 4 condition (i.e., the most misses; M no response = 1.87; $F(1, 14) = 18.97, p = .001$).

There were 9.97% anticipation errors in the attend large task and 9.40% anticipation errors in the attend small task, which did not significantly differ from each other ($t(15) = 0.35, p > .05$). The anticipation error rates across experimental conditions did not differ from each other ($F(1, 14) = 1.64, p > .05$). The anticipation error rates did

not differ across the unrelated conditions either ($F(1, 14) = 0.76, p > .05$). The false alarm rate did not differ with the dimension attended ($t(15) = 0.65, p > .05$), as false alarms occurred on average 5 trials out of 14.

Between Experiment Analyses

In order to compare performance across the different types of experiments, we conducted between experiment analyses to look at the response rates and anticipation error rates for the different tasks and experiments. These response rates were calculated as the number of trials in which subjects detected a repeat divided by the number of total possible trials, and anticipation error rates were the number of trials in which subjects responded too quickly divided by the total number of trials. We found that overall subjects had higher response rates for the picture/picture tasks ($M = 84.54\%$) than the picture/word tasks ($M = 76.87\%$; $F(1, 122) = 11.57, p = .001$), but a simple effects analysis showed that this finding was qualified by the fact that responses in the picture/picture experiment ($M = 88.32\%$) were significantly higher than in the picture/word experiment ($M = 73.19\%$; $t(41.38) = -4.82, p < .001$), and there was no difference in response rates between the picture/word lag experiment ($M = 81.04\%$) and the picture/picture lag experiment ($M = 80.23\%$; $t(56) = 0.29, p > .05$). Interestingly, response rates were significantly higher in the picture/word lag experiment ($M = 81.04\%$) in comparison to the picture/word experiment ($M = 73.19\%$; $t(54.36) = -2.26, p = .028$), however, the opposite pattern occurred for the picture/picture experiments, with the picture/picture experiment ($M = 88.32\%$) having significantly higher response rates than the picture/picture lag experiment ($M = 80.23\%$; $t(40.15) = 3.41, p = .001$). We also found that attending to words ($M = 71.58\%$) produced the lowest response rates

compared to the other conditions (*M* pictures = 82.65%, *M* large pictures = 83.97%, and *M* small pictures = 84.58%; $F(2, 116) = 7.44$, $p = .001$), but this doesn't help to explain why the response rates in the picture/word lag experiment were significantly higher than the picture/word experiment.

In analyzing the overall anticipation error rate, we found that the highest anticipation error rate occurred in the picture/picture experiment ($M = 12.10\%$), followed by the picture/word experiment ($M = 9.40\%$) and the picture/picture lag experiment ($M = 9.70\%$), with the fewest anticipation errors occurring in the picture/word lag experiment ($M = 6.30\%$; $F(3, 124) = 4.15$, $p = .008$). Combined, there were more anticipation errors in the picture/picture experiments ($M = 10.94\%$) than in the picture/word experiments ($M = 7.90\%$; $t(126) = -2.57$, $p = .011$). In contrast to the response rates, there was no difference between the anticipation error rate in the picture/word experiment ($M = 9.39\%$) and the picture/word lag experiment ($M = 6.32\%$; $t(47.55) = 1.69$, $p > .05$), and no difference between the anticipation error rate in the picture/picture experiment ($M = 12.11\%$) and the picture/picture lag experiment ($M = 9.68\%$; $t(60) = 1.70$, $p > .05$). However, there were more anticipation errors in the picture/picture lag experiment ($M = 9.68\%$) than in the picture/word lag experiment ($M = 6.32\%$; $t(60) = -2.60$, $p = .012$).

The false alarm rates also differed between the experiments ($F(3, 124) = 5.01$, $p = .003$), with the picture/picture experiment ($M = 10.02$ trials out of 21) showing the highest false alarm rate, followed by the picture/picture lag experiment ($M = 4.83$ trials out of 14), the picture/word experiment ($M = 3.85$ trials out of 14), and the picture/word lag experiment ($M = 3.69$ trials out of 14) which had the lowest number of false alarms. Combined, the picture/word experiments had a lower false alarm rate than the

picture/picture experiments ($t(126) = -3.23, p = .002$). There was also an effect of the stimuli attended ($F(3, 124) = 3.50, p = .017$), with the large pictures producing the highest number of false alarms ($M = 8.99$ trials), followed by the small pictures ($M = 5.58$ trials), and the other pictures and words were about the same ($M = 3.79$ and 3.76 trials).

Discussion

The goal of the current study was to assess the extent to which unattended information is processed and can influence responses. We attempted to overcome the shortcomings of the Rees, et al. (1999) experiment by examining the influence of the unattended information on a behavioral (motor) response to the attended information. We hypothesized that if the unattended information is processed, then by manipulating the congruency of the dimensions we may be able to demonstrate an effect on the subject's responses to the attended items. We employed overlapping picture-word and picture-picture stimuli presented in a RSVP stream, and the subject attended to only one of the dimensions with the task of detecting a repetition. We manipulated the congruency of the items in the unattended stream to examine whether this leads to priming/interference, and we varied the lag of the congruency to examine the time course of the effects. We hypothesized that if unattended information is not processed at all, then its congruency should neither speed up nor slow down responses to the attended targets. However, if unattended information is processed, then we should see either a speeding or slowing (priming or interference) of responses to the target in the attended dimension.

Studies of the picture word interference task have shown that a semantically congruent picture and word presented at the same time significantly slows picture naming. The locus of this effect is thought to be lexical, thus making it specific to the

verbal response (Damian & Bowers, 2003; Damian & Martin, 1998). However, data from the semantic priming literature show that in both verbal and motor responses the presence of a semantically related prime can significantly improve later performance. The data from the current experiments support the latter effect of semantics. In the picture word lag experiment we found that at a presentation duration of 167 ms, when subjects are attending to the picture stimuli and ignoring the word stimuli, a word that was presented but ignored has an effect on later performance. We show that a word presented four items before a congruent picture target item significantly speeds responses to that picture target compared to the condition in which the ignored word was unrelated to the picture. This indicated that an item presented 668 ms prior to the target is still receiving processing and can influence behavior. The most interesting fact about this finding is that when the word was presented the subject did not yet know what the target would be. Yet when the target's identity became known, the word was able to exert an effect on behavior and speed responses (compared to the condition in which the word was unrelated to the target). The paradox to this finding is that at a lag of three, the word showed the opposite pattern of effects (albeit not significantly), producing a slowing of responses compared to the unrelated condition, performance at lag two, and at lag four. Performance at a lag of two mimics that of lag four.

It is interesting that the only effects of picture/word congruency were seen in the picture word lag experiment. Based on the findings of repetition redundancy, we expected to see the greatest amount of priming occurring in the congruent/congruent condition in Experiment 1. The data showed some trends that seemed to indicate that when subjects are attending to the word dimension (at 167 ms duration), a set of pictures

that is congruent with the repeating word (i.e., the pictures name) produces a *speeding* of responses compared to the condition in which the picture was congruent with the first presentation of the target item (congruent R1). A different pattern emerged when the subjects were attending to the picture dimension (at the 200 ms duration). Here a set of words that was congruent with the target picture (congruent/congruent condition) produced a *slowing* of responses compared to the congruent R1 condition and the condition in which the congruent word was presented only with the target picture (congruent R2 condition). These findings tentatively indicate that the simultaneous presence of items in the unattended dimension which have the same meaning as the item requiring a response do influence performance, and thus are processed. These results have to be interpreted with caution because they did not withstand the correction for multiple comparisons. However, their presence indicates that with more power it may be possible to see reliable repetition redundancy effects.

Why do we see processing of unattended information influencing performance in the picture/word experiment only when the congruency is lagged 2 or 4 items prior to the target? One possibility relates to the results of Lavie (1995), who found that subjects were affected by irrelevant distracters only under conditions of low perceptual load (center display of one item), but not under conditions of high load. This finding can be explained by the fact that the low load condition was not attentionally taxing and possibly there were additional resources remaining to process the irrelevant distracters. However, in the high load condition, all the attentional resources needed to be allocated to searching for the target, and there were none left to process the irrelevant distracters, thus preventing them from interfering with performance. In the current experiment, the

primary task of detecting the repeated item was attentionally taxing for subjects. This can be seen in the low response rates and high anticipation error rates, especially in the attend word conditions and at the shortest presentation durations. The data from the picture word lag experiment indicate that information from the unattended channel is being processed. However, given that the primary task is so demanding the processing of that information may be decreased or may have been delayed relative to a (hypothetical) case in which the primary task was of low load. This may be why we see congruency effects only when the item was presented at some time delay before the target. Priming effects have been shown to survive a long interval between presentation of the prime and target. For example, in a stem completion task, subjects are presented with a list of words to remember and then some variable time later in a test phase are given the first few letters of a word and asked to complete the word, in which case the prior presentation of the word improves performance on the stem even though there was a time delay. It seems that the presence of the word activates the semantic representation of that word but that it takes some interval of time for that activation to cross a critical threshold which then allows it to influence the processing of the congruent picture and speed responses.

Also, as discussed in the Introduction, the reason Rees et al. did not find brain activation patterns for words when they were not attended may have been due to the fact that unattended information received reduced processing which may not be reflected in the BOLD signal. Therefore, the processing of unattended information is already reduced compared to attended processing of information (i.e., it does not receive heightened processing allowing it to enter conscious awareness). When an attentionally taxing task is added as the primary task, processing of unattended information is further reduced or

processed in a discontinuous manner. The idea that the information is processed only discontinuously may explain the lack of a congruency effect at lag 3, when lags 2 and 4 are showing a facilitation of processing. This finding requires further research.

The claim that the addition of an attentionally demanding task decreases processing of unattended information implies that both attended and unattended information are processed by similar mechanisms or in a similar way (in contrast to a dual channel approach in which attended information is processed in a primary channel and unattended information is processed in a subordinate channel). It seems that the primary task in this experiment has made it especially difficult to test the fate of unattended information. However, by decreasing the difficulty of the primary task, one may be able to examine the flux of processing of the unattended information. One way this might be done is to have subjects verbally identify a target picture which differs in color. A verbal response would suggest that the item was not just processed on a superficial level and the color makes the task of identifying (or selecting) the target easier because the color target would pop-out from the stream of distracters. In lightening the load of the primary task we may see some effects of a congruent word on performance. Future research will be needed to address this question.

One problem in conducting these types of attention studies is determining the extent to which subjects are attending to the dimension assigned and not sampling from the unattended dimension. In the current experiments we employed two methods to attempt to control for this problem. First, we used presentation durations that were determined in pilot studies to be so rapid they allowed subjects enough time to process items only in the attended dimension before the next set of items was presented. Second,

we made the number of congruency trials low in comparison to the non-congruency trials (i.e., unrelated trials) in order to make it disadvantageous for subjects to sample from the unattended dimension. In other words, it would be detrimental to task performance because on the majority of trials the unattended dimension would not contain a repeat or any item related to the target in the attended dimension. Although we employed these precautions it is possible that subjects still sampled from the unattended dimension. However, it is not likely. If subjects were sampling the unattended dimension then we should have seen very low response rates (detection rates) because subjects were not able to detect the repeat in the correct dimension. We did not find this. We had response rates in the 67%-88% range. The lowest response rate occurred in the attend word condition of the picture/word experiment and was due in part to performance in the non-word condition. Subjects found it very difficult to identify a repeated non-word and thus this condition produced a very low response rate. However, if subjects were sampling the unattended channel while preserving a sufficient overall response rate, they would have to be sampling the unattended channel randomly. This means that the likelihood that subjects would have sampled the unattended channel at the exact time the congruent item was presented would have been very low given the low frequency of these trial types and the nature of random sampling. Therefore, randomness cannot explain the significant facilitation seen at lags two and four in the picture/word lag experiment. Also, at the time the congruency item was presented in the lag experiment subjects had no idea what the target was going to be. That means that subjects would have had to hold that item in working memory until the target item was presented. Given the attentionally demanding nature of the task, this is unlikely. Taken together, it is possible that subjects randomly

sampled the unattended channel on some trials, but given the rapid presentation times and the scarcity of congruency trials random unattended sampling is not the most plausible explanation for the finding that unattended words presented at a lag of two or four items prior to a picture target speed responses to that target.

There are some other interesting findings that emerged in the current studies that warrant discussion. First, in the picture/word experiment, when subjects attended to the picture dimension at the 200 ms duration, the congruent/congruent condition had a greater number of responses than any other experimental condition. This was also the condition that showed the greatest number of congruency effects. This may be coincidental, or it may indicate that a greater number of trials per condition was needed to detect these effects. The number of subjects in each condition, 16, was chosen based on the Damian and Bowers (2003) study looking at picture-picture congruency which had twelve subjects and their picture word study which had twenty-four subjects. An experiment like the current study has, to our knowledge, never been done before, so the number of subjects needed or an estimate of power could not be based on any prior work. Some picture word interference studies employ as many as 100 subjects (Damian & Martin, 1998), so the exact number that would have yielded enough power here to find an effect was not known, but clearly more were needed. A post-hoc power analysis conducted on the observed effect sizes revealed that in order to have a power level of .70 we should have had about 26 subjects in each experiment compared to the actual number, 16, that we used.

Damian and Bowers (2003) found that picture/picture stimuli produced a significant congruency effect (speeding) of naming responses when presented at a 0 ms

SOA, and argued that this supported the idea that congruent pictures are accessed at a conceptual level. They claimed that subjects are not visually "tuning out" the distracter item, but that the pictures are not influencing performance at the lexical level either, as is true of word distracters. The 0 ms SOA condition they used is a parallel to the congruent/congruent and congruent R2 conditions used in the current experiments. Our experiments used a button press response, which did not necessarily require lexical access, but did require conceptual access because subjects had to determine whether the target had the same identity as the previous item, despite the difference in visual orientation. Using this logic we should have seen some influence of this simultaneous conceptual picture-picture processing, but we did not. There are many reasons why our picture/picture results may differ from those of Damian and Bowers (2003). It may be true that we did not find such an effect due to lack of power (as discussed above). It may be true that our failure to find an effect could argue for a different locus to explain the effects. Given the difficult nature of this task and the fact that the pictures were presented at a much more rapid rate, full processing may not have occurred at each processing step or some information may have been overwritten by the next incoming set of items. We may have seen effects in the picture/word experiment because of the automaticity of word reading (Stroop, 1935) in comparison to a slower serial processing of pictures. It may also be true that the difference in findings was due to the difference in the response measures. A naming task requires that subjects access the speech output lexicon and phonological processes in order to respond (Eysenck & Keane, 2000), whereas a button press requires that subjects activate a motor representation following the conceptual determination that the items were the same. It has been shown that reading words out

loud takes about twice as long as reading them silently, indicating that different processes are involved in these responses (Eysenck & Keane, 2000). Another difference between the Damian and Bowers (2003) study and all picture/word interference or picture/ picture studies, is that in their study the ignored item was either semantically related or unrelated to the named item. In our studies the congruent item had the same meaning as the target and all the other items in the attended dimension were from the same semantic group or a related semantic group (see Appendix A). Even though priming has been shown between semantically related items (i.e., doctor and nurse) as well as items that are the same, as in the case of stem competition, this difference in relatedness could have contributed to the difference in the pattern of results. Further studies should explore this difference.

It is interesting to note that in the picture/word lag experiment, congruency at a lag of four produced significant facilitation compared to the condition in which congruency was not present (unrelated condition), and in the picture/picture lag experiment it was in lag four that the percentage of misses (no responses) was the highest compared to all other experimental conditions. Perhaps the two tasks were producing two different effects on behavior. In the picture/word task congruency at lag 4 produced faster responses to the target, whereas in the picture/picture task congruency at lag 4 produced a withholding (or freezing) or responses. There are many reasons a subject could withhold a response so this is a challenging result to try to explain.

Another result that emerged in these experiments was the high rate of false alarms (i.e., responses when no repeat was present). This may have occurred for several reasons. First, the scarcity of these no-repeat trial types may have led the subject to believe that they were supposed to respond because most trials contained a repeat. However, this

hypothesis is unlikely, due to the high no-response rates in the other conditions. Subjects were failing to respond even when repeats were present. It could also be true that subjects were responding that they saw a repeated item when two items that were visually similar were presented. For example, if a picture of a "pot" was followed by a picture of a "pan" the subject may mistakenly respond that that was a repeat. Finally, the rapid presentation durations may have led subjects to respond as if they saw a repeat when in fact the same item was separated by intervening items. Subjective reports made during the practice trials revealed that when subjects made false alarms or failed to respond to a repeat they would realize their mistake after the trial had concluded. Therefore, it seems plausible that the rapid presentation times most likely contributed to the high false alarm rate, although this requires further investigation.

One of our sub-goals in this experiment was to examine any performance differences between the picture/word and picture/picture tasks and thus any underlying differences in the processing of unattended information. These data seem to suggest that the parameters of this paradigm are best suited to examining semantic priming in the picture/word task. The picture/picture task revealed no significant findings of effects of unattended stimuli on performance, nor any trends for such effects. Perhaps the automaticity of word reading (Stroop, 1935) makes any findings in the picture/word task resilient to the rapid presentation format, and is not affected by the attentionally demanding nature of the primary task. It may also be true that words, in comparison to pictures, produce a greater amount of semantic activation that can withstand interference from new input and produce long lasting effects.

There were sub-hypotheses regarding repetition blindness and repetition redundancy that we hoped to test in these experiments, but given the scarcity of significant results nothing notable can be said about such repetition effects. Our earlier claim that both attended and unattended information are processed by similar mechanisms or in a similar way suggests that these repetition effects could emerge with unattended information if tested in the proper way. Therefore, the possibility remains that such effects may occur in the unattended channel and future research should be done exploring these questions.

In conclusion, our goal in the current studies was to assess the extent to which unattended information is processed and can influence responses. We examined the influence of unattended information on a behavioral (motor) response to attended information in a dual stream RSVP paradigm. We hypothesized that if unattended information is processed, then by manipulating the congruency of the dimensions we might be able to detect effects on the subject's responses to the attended items. We found that when an unattended congruent word preceded a picture target by a lag of 2 items or 4 items, responses to that target picture were speeded compared to when the word was unrelated to the target. This finding suggests that the unattended information is being processed to the level at which it can influence behavior and that this processing lasts for an extended duration, with the lag 4 condition suggesting as long 668ms, after the item is presented.

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Appendix A

Picture Names and Words

Group 1: Animals, Birds, Insects, Fruits Vegetables, Weapons, Instruments, Toys

bear	chicken	apple	carrot	axe	drum	ball
camel	duck	banana	celery	bottle	flute	balloon
cat	eagle	cherry	corn	cannon	guitar	bat
cow	ostrich	grapes	lettuce	chain	harp	bell
deer	owl	lemon	onion	gun	piano	book
dog	peacock	orange	peanut	scissors	trumpet	box
donkey	penguin	peach	pepper		violin	clown
fox	rooster	pear	potato			doll
frog	ant		pumpkin			football
giraffe	bee		tomato			kite
goat	beetle					sailboat
gorilla	fly					swing
horse	spider					top
kangaroo						wagon
leopard						whistle
lion						
monkey						
mouse						
pig						
rabbit						
raccoon						
sheep						
skunk						
squirrel						
tiger						
turtle						
zebra						

Group 2: Kitchen, Furniture, Body Parts, Tools, Clothes, Buildings, Vehicles

bowl	ashtray	arm	chisel	belt	door	airplane
broom	bed	ear	hammer	blouse	doorknob	bicycle
cup	chair	eye	ladder	boot	lock	bus
fork	clock	finger	nail	cap	window	car
pan	couch	foot	nut	coat		skate
glass	desk	hair	pencil	dress		sled
kettle	dresser	hand	pliers	glove		train
knife	lamp	heart	ruler	hat		truck
pot	stool	leg	saw	jacket		
spoon	table	lips	screw	pants		
stove	vase	nose	wrench	ring		
toaster		thumb		shirt		
		toe		shoe		
				skirt		
				sock		
				sweater		
				tie		
				vest		

Appendix B

Non-words used in Experiment 1

Group 1:

pliphed
slibed
strawgs
gourths
spruled
swoarc
woughbed
sheuge
phlylde
ghwauth
shrofe
twuid
spumfs
phynge
jeufth
droills
leabbed
cloamth
plognth
yised
slarrs
twilch
sckoann
sproogn
yorped
kournths
hounce
skressed
swounns
bomf
prerzed
dreighms
stewck
kilched
crauks
phloids
gwudds
cwypes
slilled
garlt
struiked
blance
vornde
cradds
meebe
skwourp
chovved
draide
scwebe
scuick
thys
yeimbth
ghlylbed
gronsed
ghweas
spranxed
veffs
bulmb
dould
biltch
plub
tighced
heiggs
stob
plalped
sproules
sheavved
ploile
smildged
theivved
scarnde
dweigued
scirnt
screksts
ghwylte
frounsed
ghrounse
dwoaced
spreaced
ghlep
klercks

Group 2:

blorgues
swawnch
wheef
screefes
vylthed
whulph
cwapts
sweufth
gnilled
skolts
phlawmb
craunns
faughnth
slighfed
scwoalds
wheust
frutts
cronts
droughd
sprine
jeetched
gweuck
baiched
phoabb
couts
spysked
dweish
ghrighf
knuilt
wrawlte
frarves
wrascked
trisped
druf
choarls
kwieve
smawpth
geibbed
phraulds
thrargue
moodged
freegged
porche
koarnds
snaifes
skeaffth
thapte
phloaff
spleign
feugs
ghrawks
ghroarts
bease
klylk
thraithe
koughmed
hisped
brerphed
joocked
ghrict
flaphths
kruinnth
wipsed
rewnd
cwirphed
eelt
zeegues
saughmn
floofe
phliest
trylned
thwoned
douled
knenced
snoatts
sckached
drazz
thwirfed
baughnd
joopth
deighf
jynts