Inattentional Amnesia

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Imagine that you are on the street and someone pulls you aside to ask you directions. You begin to engage this person in conversation. For mysterious reasons, in the middle of this conversation, workers, carrying a door, walk between you and the other person. When the door is gone, the original person has been replaced by a different person. Would you notice if Stranger One was replaced by Stranger Two? The intuitive answer is "Of course, I would." How could you fail to realize that you were no longer talking to the same person? The empirical answer, from a clever experiment by Dan Simons and Dan Levin (1997) is that people fail to notice this change about 50% of the time. Surprising as this finding might be, it is not an isolated phenomenon. In recent years, a growing number of reports have seemed to show that we see much less than we think we see. Simons and Levin have produced a number of variations on this basic theme. In one series of experiments, subject watch a video tape of a conversation. The camera cuts from one speaker to the other. Speaker One is sitting at a table. She pours herself a cup of Diet Pepsi. The camera cuts to Speaker Two. When the camera return to Speaker One, the Pepsi bottle has been replaced with a cardboard box. Subjects might remember that Speaker One poured herself a drink but they frequently fail to notice that the bottle has vanished .

Grimes obtained a similar effect when he changed the contents of images during eye movements. He found that observers were strikingly insensitive to substantial alterations in the content of scenes. These were unsubtle changes such as trees disappearing from front yards. Blackmore et al. did a different version of this experiment. In their study, subject viewed one image. The image was then moved to a new location. Subjects had to move their eyes to re-foveate it. They then needed to decide if the second image was the same or different from the first. Performance was quite poor. Again, subjects missed substantial changes from one image to the next. Irwin and his colleagues have asked, in various ways, what information about a scene is preserved when observers make an eye movement . For instance, they have asked how well subjects perform tasks that require the combination of information from successive fixations. They find that subjects perform quite poorly at such tasks and they conclude that very little visual information is preserved across saccades. Henderson reaches a similar conclusion. Information about the goal of the eye movement is retained but there is little evidence for the idea that a rich visual percept is built up over a series of fixations .

Rensink, O'Reagan, and their collaborators have shown that observers can fail to report changes in an image even if those changes are not made during an eye movement or a camera movement . In one version of their experiment, observers look at a natural scene. At regular intervals, the scene is very briefly replaced by a white field. When the scene reappears, *something* has changed. The observer's task is to find the change which oscillates back and forth from frame to frame. Observers are surprisingly bad at this task . Even though they may be looking at the images for several seconds, subjects fail to notice that jet engines appear and disappear from an airplane. They fail to notice that a bridge crosses a pond on the even-numbered frames and stops in the middle of the pond on the odd frames. Observers notice the change only if they happen to be attending to the changing object or location from frame to frame. It is not necessary to blank the entire screen. A distracting "mudsplash" will produce the same effect . As in the other examples, the implication would seem to be that we actually see far less than we think we see when we look at a scene .

Arien Mack and Irv Rock propose a way of understanding such phenomena that they call "inattentional blindness". The hypothesis is that we do not consciously perceive objects to which we have not attended. Their own evidence for this hypothesis comes from a line of heroic experiments - heroic because each experimental session yields just one trial per observer. Observers are asked to view a briefly presented "cross" and to judge if the vertical or horizontal component line is longer. After a few trials of this sort, comes the critical trial. On this trial, some irrelevant stimulus is flashed in one of the quadrants formed by the cross. After the trial, observers are asked if they saw anything out of the ordinary. Observers fail to report stimuli that are easily seen if observers are aware that such stimuli might appear (hence, one critical trial per observer) . Mack and Rock argue that, in the absence of attention, the irrelevant stimuli never rose to the level of conscious perception.

An experiment by Joseph et al. seems to support this view. In their experiment, using a rapid serial visual presentation (RSVP) task at fixation, they produce an "attentional blink" (see Chun & Potter, 1995; Raymond, Shapiro & Arnell, 1992; and see the chapter by Shapiro and Luck in this volume). If a visual search stimulus is presented during the 'blink', subjects are unable to successfully detect a target of one orientation among homogeneous distractors of another orientation. It could be argued that the attentional blink task entirely consumes attention during the blink and, as a result, the search stimulus is simply not seen - "inattentional blindness".

We can apply the inattentional blindness argument to the first examples discussed in this chapter. Why don't observers notice changes in unattended objects when those changes are made during eye movements or under cover of a distracting event like a screen flash or mud splash? Inattentional blindness argues that the changes are not seen because the stimuli that changed were not attended and, thus, not consciously perceived. On the other hand, inattentional blindness is not an entirely convincing explanation of the Simons and Levin or Rensink et al. experiments. The stimuli are present for a relatively long time in these tasks. Surely, observers in the Simons and Leven experiment were attending to the person who was asking them directions. Surely that person was perceived. Why, then, was a change in his identity not noted? Moreover, inattentional blindness seems at odds with introspection. When we look at a scene, we seem to consciously perceive *something* throughout the visual field. Even at stimulus onset, conscious perception does not seem to be restricted to the object of attention. This sort of introspective argument is unsatisfying, because it is extremely difficult to test experimentally. Indeed, there are serious problems with any experimental effort to directly ask subjects if something is consciously perceived without attention. The direct approach would be to could ask subjects to attend to visual stimulus "A" and report about the perception of stimulus "B". However, this is proves to be impossible because the demand to report on B directs attention to B. If you do not attend to a stimulus, then you cannot report on that stimulus regardless of whether or not you saw the stimulus. Thus, the problem of perception without attention is a difficult experimental nut to crack, if one is willing to accept that it is possible to see stimuli that cannot, for one reason or another, be reported,

The widely employed solution to this methodological problem involves presenting a stimulus, arranging for the subject not to attend to that stimulus, removing that stimulus and then, after the unattended stimulus is gone, asking the subject to report on its properties. The usual finding, as seen in the examples given above, is that subjects are very poor at after-the-fact reporting on the properties of unattended stimuli. Note, however, that an inability to report is not the same as an inability to see. Sperling's made this point forty years ago. A subject, asked to report all the letters in a briefly flashed, 12-letter display, could report only about 25-30% of the letters. However, the subject would do much better if cued after the display was gone to report on a the letter at a specific location.

Sperling's subjects responded after the stimulus had been removed but subjects could still attend to the icon if not to the physical stimulus. All of the experimental examples given thus far in this paper are experiments that involve reporting after the removal of the stimulus and after the destruction or dissipation of any icon representation. In the Mack and Rock experiment, observers are asked if the saw anything unusual on the previous trial. In the Simons and Levin experiment, subjects must compare the current speaker with a speaker who was present before the door moved past, and so forth. Even when the subject knows the question, report is made after the stimulus is gone (e.g. the Joseph et al. experiments). The common thread in these experiments has been that unattended stimuli cannot be accurately reported after they are gone. Unfortunately, there are at least two plausible explanations for this failure. 1) As suggested by the inattentional blindness hypothesis, the stimuli might not be *seen* if they are not attended. 2) Alternatively, the stimuli might have been seen but not *remembered*. In this volume on fleeting memories, I wish to argue that the explanation of these apparent failures of perception is not inattentional blindness but *inattentional amnesia*..

The Inattentional Amnesia Hypothesis

The inattentional amnesia hypothesis has four parts:

1) Under normal circumstances we consciously perceive visual *stuff* at all locations in the visual field (Visual "stuff" will be more precisely defined below.).

2) At the current locus of attention, visual information can make enhanced contact with other mental processes. This permits, for instance, object recognition and transfer into memory. Attention may change the visual representation so that things look different while attended. Overt responses, from eye movements to key presses, demand attention.

3) The present conscious visual representation is composed of the visual stuff of #1 and the effects of attention as sketched in #2.

4) This visual representation has no memory. It exists solely in the present tense. When a visual stimulus is removed, its contents are lost to the visual system. Similarly, when attention is deployed away from some previously attended object or locus, no trace of the effects of attention remain in the visual representation.

If vision has no memory and if attention is the gateway to other mental representations, it follows that unattended visual stimuli may be seen, but will be instantly forgotten; hence, inattentional amnesia.

In the bulk of this chapter, I will describe experiments that motivate the various pieces of the inattentional amnesia hypothesis. At the end, we will return to the phenomena described above and show how they can be understood in this context.

Preattentive vision and visual "stuff"

The greater part of research on visual perception deals with what can be called "attentive vision". A stimulus is placed before an observer and the observer is asked to respond to that stimulus. The situation requires and expects that observers will focus attention on the stimulus. It is somewhat more difficult to assess visual function away from the present locus of attention. For more than 20 years, visual search experiments have been among the most effective tools for examining the nature of "preattentive vision", vision prior to the arrival of attention. In standard visual search experiments, observers look for one item, the "target" among a variable number of "distractor" items. The search display can be briefly flashed, in which case the dependent measure is accuracy. Alternatively, the display can remain visible until a response is made, in which case the dependent measure is reaction time (RT). Our experiments use RT methods.

As shown in Figure One, search tasks differ in their efficiency. "Feature" searches are searches where the target is distinguished from the distractors by a unique basic feature. In Figure One, the feature is orientation and the target is uniquely horizontal ("shallow" may be a more accurate description . Many feature searches are very efficient, with RT essentially independent of set size. This independence suggests that all items can be processed at the same time ("in parallel") . There are, perhaps, a dozen basic features that support efficient search . These include color, orientation, size, various cues to depth, etc.

Parallel processing of basic features across the entire stimulus is thought to occur before any attentional bottleneck in processing. Thus feature processing is said to be "preattentive" . Attention seems to limit processing to one or, perhaps, a few objects at a time , possibly by constricting receptive fields in some cortical areas to cover only the attended item(s) .

This is not the place for a full discussion of the properties of preattentive vision. However, it is worth noting that there is more to preattentive visual processing than parallel extraction of a dozen basic features. For our purposes, the most important of these properties is that preattentive processing includes some division of the image into candidate objects . Attention is probably deployed from preattentive object to object rather than from location to location , though it is possible to direct attention to a location, too . Moreover, there is some evidence that preattentive processing is sensitive to the structure of objects and can assign one attribute to the whole object and another attribute to a part. As an example, while it is difficult to search for a target defined by two colors (e.g. the item that is red and green , preattentive processing makes it relatively easy to find a whole item of one color with a part of another color (e.g. the red item with a green part .

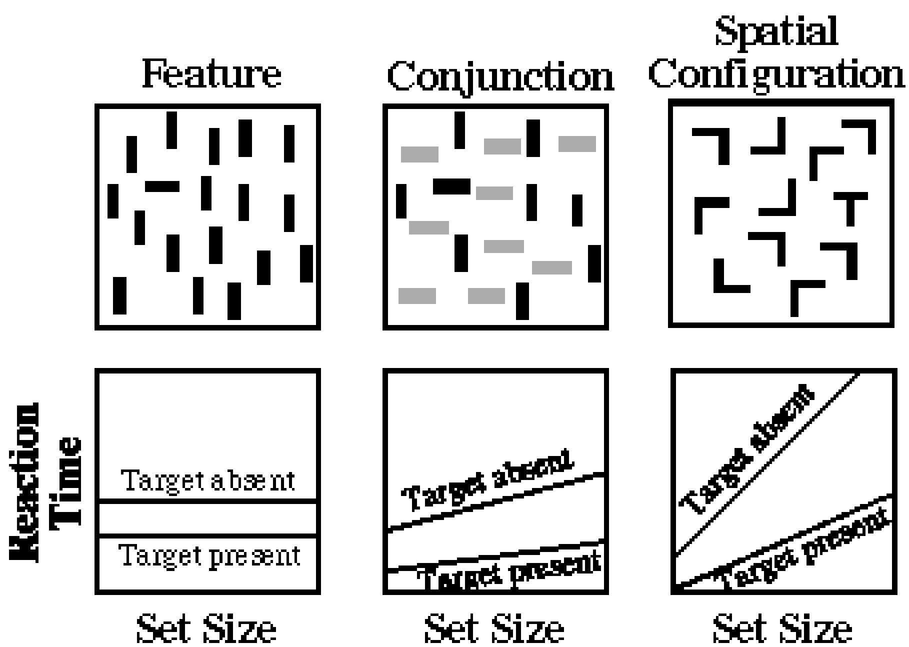


Figure One: Typical searches and patterns of RT data.

Returning to Figure One, most searches in the real world are conjunction searches. In these searches, no single feature defines the target but basic feature information is part of the definition of the target. Looking at the middle panel of Figure One, the target is black and horizontal. We probably do not have preattentive "black horizontal" processors . However, if a color processor *guided* attention toward black items and an orientation processor guided attention toward vertical items, the intersection of those two sources of guidance would tend to direct attention toward black vertical items. The result is relatively efficient search for conjunctions of basic features. This idea that preattentive processes can guide attention in a useful manner is the heart of the Guided Search model (Wolfe, 1994; Wolfe, Cave & Franzel, 1989; Wolfe & Gancarz, 1996; . For present purposes, the important point is that the target is not identified until attention is deployed to the target object. Only with attention can the relationships between basic features be used as a basis for an overt response.

The role of attention is more marked in tasks where basic feature information is of no use, as in the *spatial configuration* search in the third panel of Figure One. Here the target is a "T" and the distractors are "L's". Target and distractors have the same basic features - a vertical and a horizontal line. Preattentive processes cannot guide attention in this case and search proceeds in what appears to be a serial manner from item to item until attention stumbles upon the target .

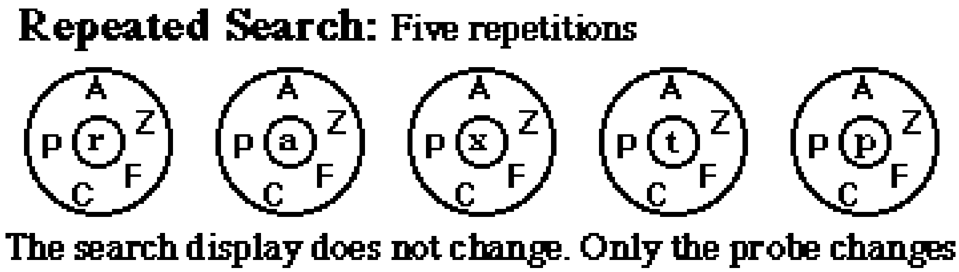
Whether search is efficient or inefficient, the items in a search display are present in the conscious visual representation prior to the arrival of attention. A glance at the T vs. L search in Figure One makes it clear that there are several vertical and horizontal items present. You see them but do not know if a specific item is a T or L until attention visits that item. This illustrates the first three parts of the inattentional amnesia hypothesis. 1) We see something everywhere. That "something" is preattentive vision. 2) Attention can take the preattentive feature information and create a different perception, and 3) the current contents of the visual representation are preattentive vision augmented by the current work of attention.

Post-attentive vision

From the vantage point of a book on fleeting memories, the interesting questions begin to arise not in preattentive or attentive vision but in what can be called 'post-attentive vision' . When the eyes first open on a new scene, preattentive processes extract features and assign them, loosely, to preattentive objects. Typically, attention will be deployed to one object. That act of attention permits the features of the object to be organized and processed in a way that permits object recognition. The attended object is perceived differently from the not-yet-attended objects in the scene. Assuming this to be the case, what happens when attention is deployed to the next object? Does the visual representation have a *memory* of the work of attention? The possibilities can be illustrated by analogy. Consider a model airplane. In its 'preattentive' state, it is a collection of pieces in a box. When a child directs 'attention' to those pieces, they can be formed into a recognizable object. When the child's attention is directed elsewhere, the model remains glued together. This post-attentive representation has a memory for the effects of attention. Alternatively, consider a set of juggling balls. When our talented child directs attention to the balls, they can be juggled into a recognizable figure. However, when the child's attention is directed elsewhere, the balls no longer describe an oval in the air. They return to their unjuggled, preattentive state. This post-attentive representation has no memory.

Measuring Post-attentive Vision - The Repeated Search Task

In a series of experiments, we have asked if the visual representation has any memory for the perceptual effects of attention. We find that the answer is "no". When attention is deployed elsewhere, the visual representation of an object appears to revert to its preattentive state. The first series of experiments used a repeated search method. The basic stimulus and experimental design are illustrated in Figure Two.



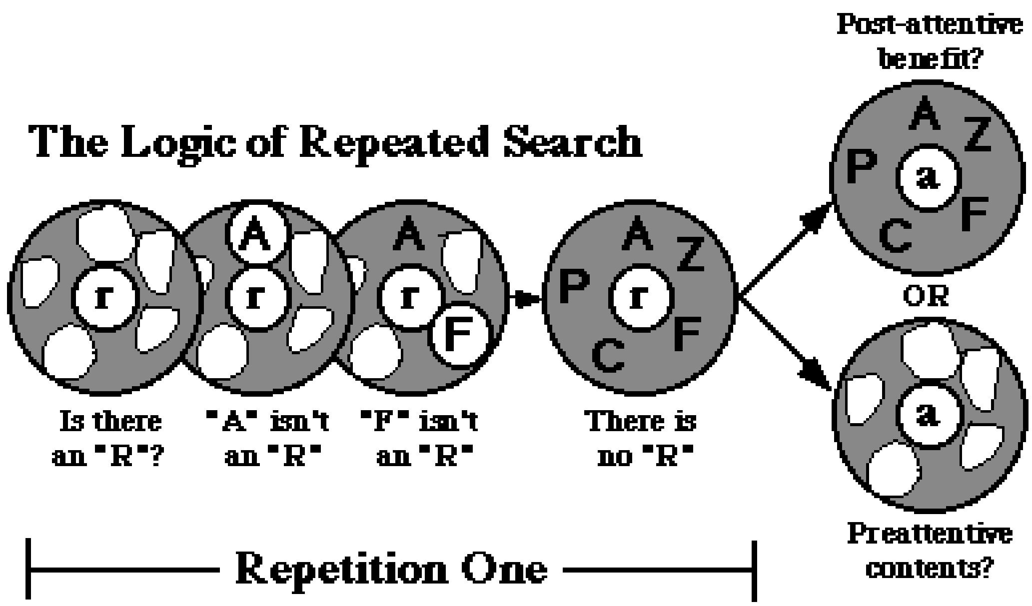


Figure Two: The repeated search paradigm. The top panel shows a sequence of five, repeated searches through a single display. The bottom panel shows the presumed action of attention during the first search.

In repeated search, the search stimulus remains the same over several trials. In the version shown in the top part of Figure Two, five letters form the search display. These are presented in a circle around fixation. At the center of the display, a probe letter is presented. The observers task is to determine if the probe letter can be found in the search array. Thus, in the first trial shown in Figure Two, the probe is an "r" and the answer is "no"; it is not present. The second probe is "a", which is present, and so forth. The post-attentive logic of this experiment is shown in the second part of Figure Two. When the display first appears, the letters are represented preattentively. The blobs in the figure denote pre-attentive object files - shapeless bundles of basic features . As time progresses from left to right in the figure, attention is deployed to first one and then another object. Attention allows the letter to be read and allows the observer to determine that no "r" is present in the display. After the subject responds to the probe letter, "r", it is replaced with an "a" probe. There is an "A" in the display. Presumably, it must have been identified in order to determine that it was not an "R" in the previous trial. Does this act of attending and identifying the "A" on one trial have any impact on the course of search for the "A" in the next? Put another way, does the visual stimulus, "A", retain some post-attentive quality that makes it easier to find on the next trial or does the display revert to its preattentive state?

Note that, for the logic of this experiment, it does not really matter if one holds that attention is deployed in series from item to item (as proposed here) or if one believes that attention is deployed in parallel across all items. In either case, for the "r" to be rejected, all letters in the search display must be identified. Does that speed subsequent searches through the same display?

In the actual experiment, observers searched through the same display five times. The search display could contain either 3 or 6 items. The center of each item lay on an invisible circle of radius 2.6 deg. The probe, identifying the target on each trial, was presented in the circle at the center of the display. On 50% of the trials, the probe item was present in the search display. Subjects responded by pressing one key if the target was present and another if the target was absent. Reaction time and accuracy were recorded. Accuracy feedback was given by coloring the central circle after each repetition - blue for correct responses, red for incorrect. Subjects were tested for 20 practice and 100 trials (or 5 x 20 = 100 and 5 x 100 = 500 total searches). For the version presented here, the first test probe appeared 300 msec prior to the onset of the search display and subsequent probes appeared 50 msec after the previous response was recorded. We have repeated the experiment with the first probe appearing at the same time as the search display and with longer intervals between response and the next probe. These manipulations do not alter the basic results described below. The search display remained continuously visible with no change during the five search repetitions. Experiments were run on Macintosh computers using MacProbe software [Hunt, 1994 #3325].

We have performed this experiment with letters, meaningless closed curves, meaningful pictures, and conjunctions of color, orientation, and size. In all versions, the results were similar to the results for conjunction stimuli shown in Figure Three. The conjunction stimuli could be red, green, yellow, or blue rectangles that could be oriented vertically, horizontally, or obliquely. The rectangles could also be large or small.

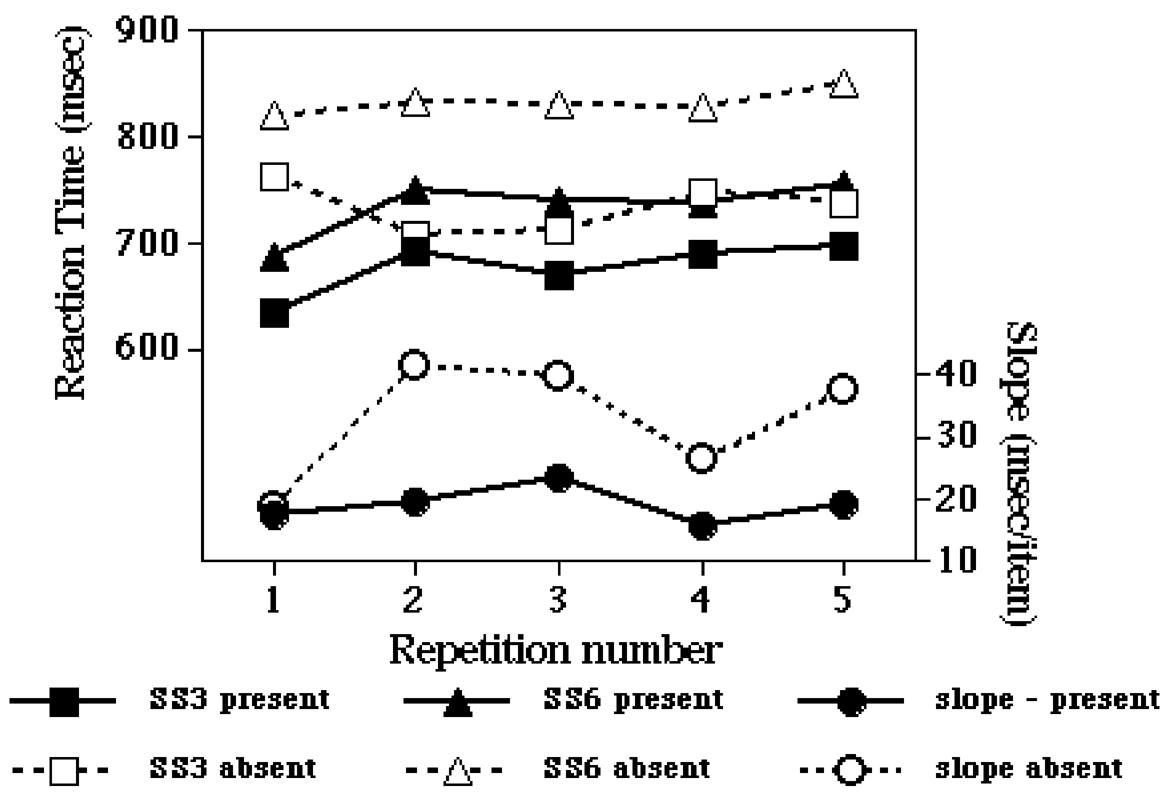


Figure Three: Repeated Search - Results for conjunction stimuli (data from Wolfe, 1997)

Looking first at the reaction time data, it is clear that the RTs do not change markedly as a function of repetition. More important than the absolute RTs, however, are the slopes of the RT x set size function since these slopes are the measure of the efficiency of visual search. The slope is derived from the difference between RTs for set sizes 3 and 6. The RT graph shows that this separation is not decreasing. The slopes, themselves, are plotted in the lower portion of Figure Three. On the first appearance of the stimuli, search is quite inefficient. Though many conjunction searches are very efficient , this search would not be expected to be efficient because of high distractor inhomogeneity and, more importantly, because the target changes on each trial (inconsistent mapping - . Here, search is inefficient on repetition one and repeated search does not improve efficiency.

This seems surprising because observers must have been learning something about the display. Why weren't they using this knowledge to improve search efficiency? Perhaps the observers did not have enough exposure to the search display. To test this hypothesis, we had observers search 400 times through the same set of three or five letters. As in the previous experiment, the search display remained unchanged - this time through all of the 400 trials. By the end of the 400 trials, observers were *very* familiar with the stimuli. If asked, they could easily recite the three or five letters they had been examining. Nevertheless, while search efficiency improved a little, slopes were still in the decidedly inefficient range of > 50 msec/item after 400 trials.

Knowing the letters in the search display did not improve search efficiency because knowing is not seeing. If an observer knew that the letters in the display were C,V, & N, she could search through that remembered set rather than searching through the visual display. However, that memory search would proceed at a rate equivalent to 30-40 msec/item - a rate not notably different from an inefficient visual search. In fact, our repeated search paradigm reveals the unexpectedly impoverished state of post-attentive vision precisely because memory can be of so little help. In more realistic search tasks, memory is useful. If I want to find a book on a colleague's shelf, I must engage in a fairly inefficient visual search. If I want to find a book on my shelf, my search is speeded by my knowledge of the layout of my library. I don't <u>see</u> my shelves differently from the way I see my colleagues' shelves. I <u>know</u> more about them. The repeated search tasks employed here do not benefit from memorization of the display because memory access is no more efficient than visual access for these tasks. For the present purposes, the important point is that repeated application of attention to a search display does nothing to the visual representation that makes search more efficient.

Once the search display has been committed to memory, the visual stimulus may actually serve to interfere with search. For example, after 400 trials of search through the same set of letters, we removed the search display and asked observers to continue to respond to the probes based on their memory for the contents of the display. The resulting RTs were about 100 msec *faster* in these memory searches than the visual searches. The slopes of the memory search functions were 30 msec/item for items in the memory set and 50 msec/item for items that were not in the set. These are comparable to the results of Sternberg . A series of experiments comparing memory search and visual search suggests that the visual search display acts to mask the probe at the center of the display .

<u>A second repeated search task</u>

We replicated the repeated search result with a modified version of the task. The goal of the new task was to unconfound trial number and the pre/post-attentive status of an item. That is, in the original version, all of the items are represented preattentively at the onset of trial one. No new items could appear after that. The visual representation of the display can only become increasingly post-attentive. Figure Four illustrates a method that allows new items to appear during a session.

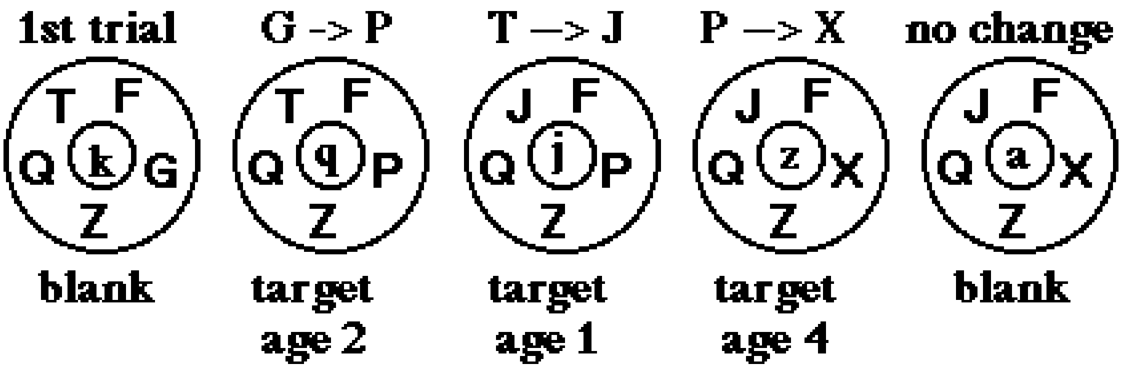


Figure Four: A second repeated search paradigm.

The observer's task is the same as in the previous version of repeated search. Is the probe letter present in the search display? In this version, however, one item in the search array could change on each trial. In Figure Four, the changes are described above each display. On each trial after the first, each letter in the search display was moved by a small amount. On half of the trials, one of these letters changed to a new letter. The movement of all letters masked the transients that would otherwise have alerted subjects to the change in one letter . Thus, from Trial 1 to Trial 2, the "G" becomes a "P. On some trials (e.g. trial 5 in Figure Four) nothing changed. In the figure, the "age" of the target, shown below the display, is the number of trials that the target has been present in the display. With this method, age of the target is uncoupled from trial number. It becomes possible to have targets of age 1 appearing throughout a series of trials (e.g. trial 3 of Figure Four).

In this experiment, no feedback was given between repetitions and a 500 msec interval was placed between the response to trial N and the presentation of the target probe for trial N+1. Targets were presented on 60% of trials. After 30 practice searches, each subject was tested for 2 blocks of 800 trials - one with set size 3, the other with set size 5. Other details can be found in Wolfe (1997a).

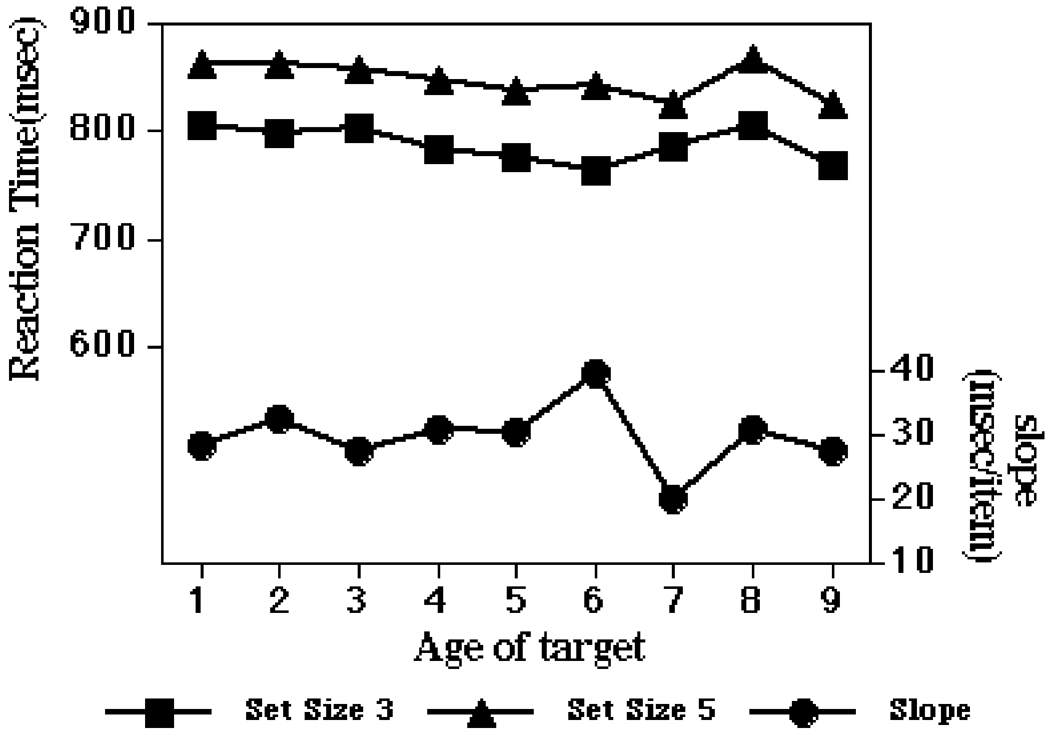


Figure Five: Repeated Search - Results for conjunction stimuli

(data redrawn from Wolfe, 1997)

Since we are interested in the age of the target, it is only the target present trials that are of use here. Figure Five shows the results, averaged over ten observers. It makes very little difference if the target item is new to the display or if it has been present for several trials. The time required to find a letter is about the same whether that letter is represented preattentively or post-attentively.

The results of the repeated search experiments suggest that attention to an item does nothing persistent to the visual representation of that item; at least, nothing that can be used to make visual search more efficient. Couched in terms of fleeting memories, this means that the visual representation's memory for the effects of attention is fleeting, indeed. Attention does something to the representation of items. In many cases (e.g. letters), items are not recognized until attention is applied to them. Once attention is deployed elsewhere, however, any trace of that attentional effect on the visual representation vanishes very rapidly.

Curve Tracing - A different post-attentive paradigm

While the results of the repeated search experiments seem very clear, it is unwise to base conclusions on a single line of research. Accordingly, we have performed another series of post-attentive experiments using an entirely different task. Here we use a curve tracing task introduced by Jolicoeur et al. . The basic idea is illustrated in Figure Six.

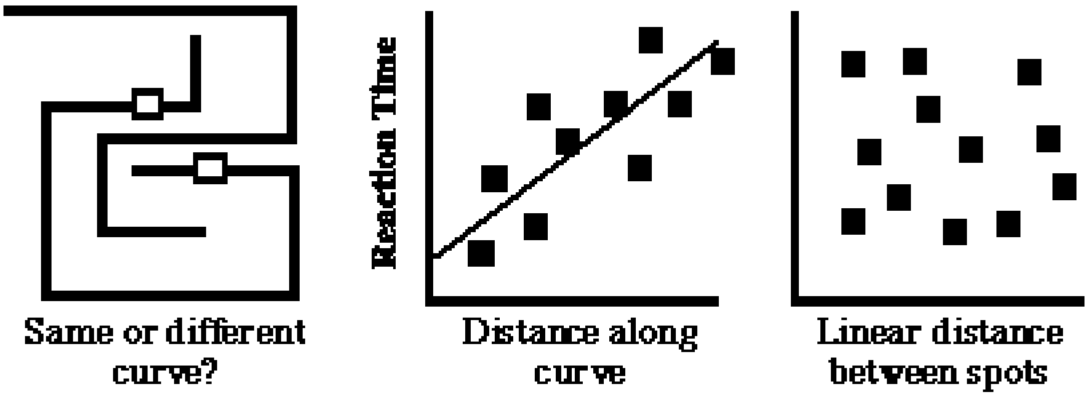


Figure Six: The Jolicoeur et al. (1986) curve tracing paradigm. RT to determine if the spots are on the same curve depends on the distance along the curve between the two dots and not on the physical separation of the dots.

Jolicoeur's subjects were asked to determine if a pair of dots were on the same curve or on different curves (as in Fig. 6a). The basic finding was that reaction times depended on the distance along the curves and not the linear distance between the dots. Jolicoeur et al. proposed that the task was performed by having an attentional operator, a "visual routine", move along the curve from one dot to the other. We reasoned that this could be a useful task in an investigation of post-attentive vision. If attention changed the visual representation of the curve, then the dependence of RT on distance might be reduced with extended exposure to the same curves. The basic task is shown in Figure Seven.

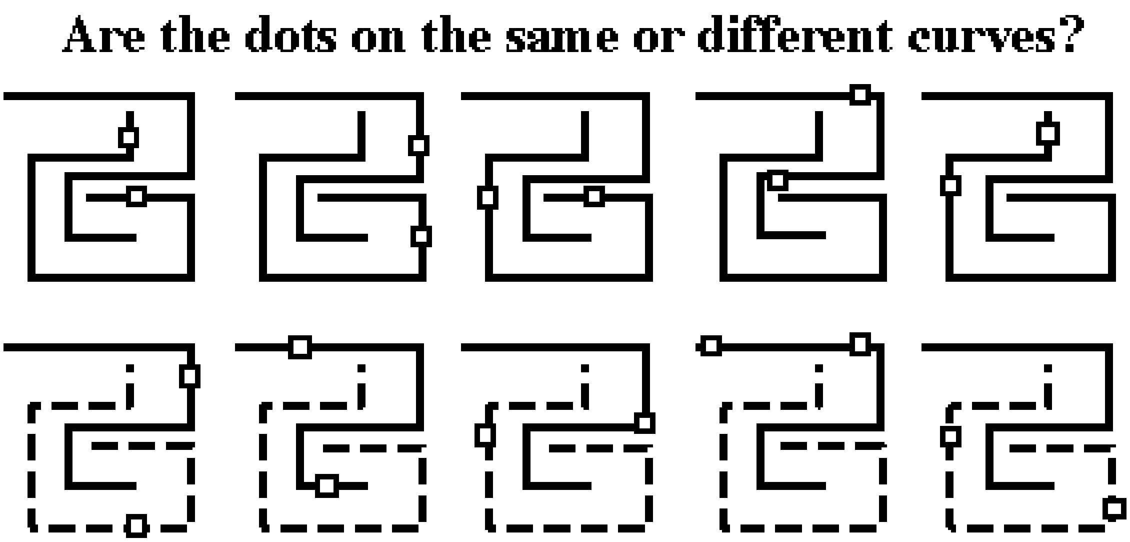


Figure Seven: The repeated curve tracing task.

In the upper row, we have an example of the repeated curve tracing task. In the actual experiment, the curves remained fixed on the screen. The dots changed position from trial to trial. Subjects made a forced-choice response that the dots were either on the same or on different curves.

What might we expect if post-attentive vision showed the persistent effects of attention? Perhaps attention serves to individuate one curve from the other. If a subject knew that one dot was on curve A and the other was on curve B, we can presume that it would not be necessary to trace the curves. This would be akin to asking if two people reside in the same town. If you say that one person is in California and the other in Massachusetts, you do not need to scan the town. You simply know that the people are not in the same town. In the context of curve tracing, we can examine the consequences of individuating the curves by using curves of different colors as shown schematically in the lower portion of Figure Seven. With different color curves, tracing is not necessary. If one dot is on a yellow curve and the other is on a blue curve, it is safe to say that they are on different curves. Can attention "paint" the curves so that tracing becomes unnecessary following extended exposure to one set of curves?

The methods were similar to those used for the repeated search task. Subjects performed five trials with each pair of curves. The curves were unchanging during those five trials. Only the position of the dots changed. Ten subjects ran a total of 500 trials with curves of the same color and 500 trials with each curve having a different color.

Our experiment replicated the basic findings of the original Jolicoeur et al. (1986) study. RTs over 5000 msec were discarded. The average correlation of RT with distance along the curve (r-sq = 0.14) was significantly greater than the correlation with the linear distance between points (r-sq = 0.025; paired $t(9)=6.75$, $p<0.001$). Our particular interest is in the efficiency of the task as reflected in the slope of the function relating RT to distance along the curve. The average slopes are shown in Figure Eight.

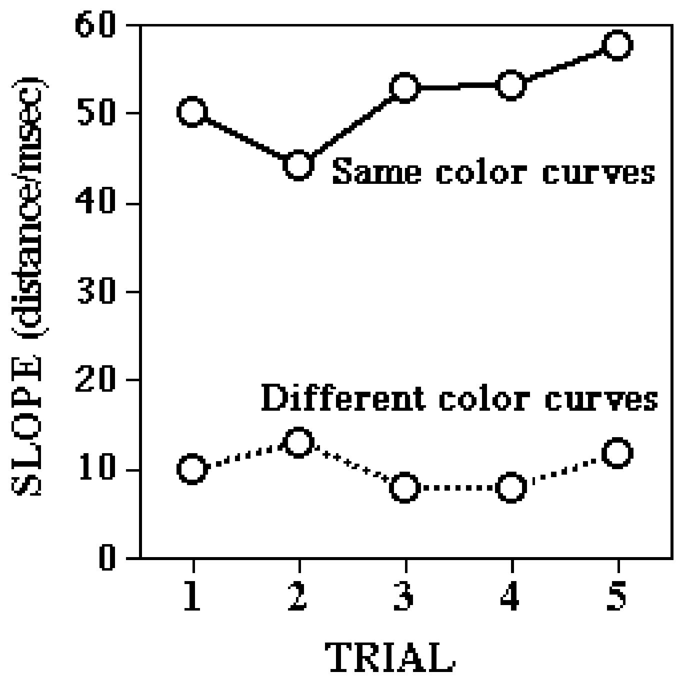


Figure Eight: Repeated curve tracing. Subjects trace no faster on the fifth repetition than they do on the first.

There is no improvement in the efficiency of the curve tracing task as a function of repetition. The Different Color condition produces faster tracing (shallower slopes) than the Same Color condition. This means that there was room for improvement in the same color condition but no improvement is seen. One might wonder why there is any evidence for tracing in the Two Color condition. It is hard to see why subjects should bother tracing at all. However, Pringle and Egeth have shown that slopes are greater than zero even for very simple stimuli. Perhaps some tracing is automatic and mandatory.

As in the repeated search case, we were concerned that we had not given post-attentive vision enough of a chance to show the enduring benefits of attention. Accordingly, we had nine subjects do the curve tracing task 100 times for each of 10 curves. If we compare the first 25 trials to the last, we see that there is little change (Figure Nine). The slowest subjects show some improvement. However, performance with the same color curves never approaches the efficiency of performance with the different color curves.

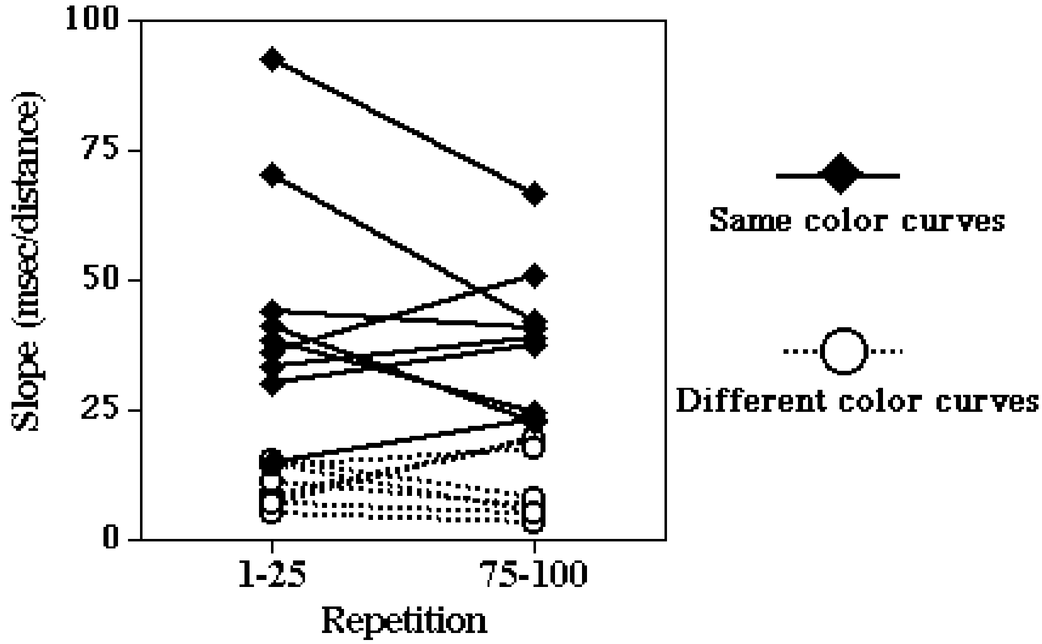


Figure Nine: One hundred trials do not eliminate the need to trace a curve. Each line connects one subject's slope value for the first 25 trials with that subject's slope for the last 25 trials.

To determine if two dots lie on the same line, it may be necessary to use an attentional operator to trace the curve from one dot to the next. The results of these experiments suggest that any such attentional tracing leaves not a trace behind. The tracing done on one trial must be done again on the next. There is no evidence for a post-attentive benefit in curve tracing.

<u>*Discussion*</u>

What does vision remember?

Evidence, converging from many experiments in many labs, argues that vision does not remember very much, if anything. Is there a spatiotopic visual representation that remembers the contents of one fixation and fuses those contents with the contents of the next fixation? We get a negative answer from almost all of the recent experiments on transsaccadic memory. Subjects are poor at noticing changes in a scene when they move their eyes over the scene or when the scene moves and the eyes follow . Subjects are poor at noticing changes in the contours of an object across fixation .

They do not integrate patterns over fixations . If the visual stimulus does not move, subjects still fail to notice large changes to items that are not the present subject of attention . These changes can include alterations in basic, preattentive features like color. In one of Rensink's demonstrations, for example, a boat changes from blue to yellow without being immediately noticed. This argues that even the preattentive contents of the image are not remembered from one moment to the next. In one frame you may see a blue boat. In the next frame you may see a yellow boat. However, unless you were attending to the color of the boat, no memory of the boat's previous color is available to compare with the boat's present color.

If you attend to the boat over the course of the change from one image to the other, you can encode the fact that the boat was blue and is yellow and, therefore, must have changed color. That attention, however, is not changing the visual representation. The post-attentive experiments described in this chapter find no persistent visual effects that can be used to speed visual search or curve tracing. Memory for the color of the boat or, indeed, for anything else seems to be quite separate from the actual experience of seeing. Vision exists in the present tense. It remembers nothing.

Note that it is rather hard to explain something like the failure to notice a changing boat color by saying that the color was not seen. If you ask subjects about the gist of the scene, they will tell you that the picture included a boat pulled up on the shore. How could the boat be seen without seeing its color? What was seen at the location of the yellow (or blue) pixels that made up the side of the attended and perceived boat?

How long is the present tense?

It is not entirely fair to say that vision has no memory. If a visual stimulus is extinguished, its effects remain for some period of time. One hundred msec might be a good estimate for the duration of this fleeting visual memory (the "sensible present" in James terms - p608, 1890). For example, Phillips , had subjects compare two random dot patterns. If these patterns were briefly presented and separated for less than 100 msec, subjects could detect small changes between the patterns, suggesting that they could compare all of the past stimulus with all of the present stimulus. As the ISI increased, performance dropped markedly and subjects behaved as though only a small subset of information on the first frame was available to be compared to the second frame. As a quite different example, consider that for durations of less than 100 msec light intensity and duration trade-off so that 10 units of light for 100 msec looks like 100 units presented for 10 msec . For the present argument, nothing very important rests on the duration of the present tense. The visual representation probably persists for some short period of time beyond the extinction of the physical stimulus. However, by the time the subject can be asked about the contents of that representation, it is gone.

But what about cases where perception takes time to develop?

There are a number of famous cases of visual stimuli that do change with continued inspection. Examples would include the Dalmatian dog picture that looks like black and white blobs until you "get it" and complex stereograms like Julesz's spiral or the "Magic Eye" autostereograms . These cases seem to show exactly what the post-attentive experiments do not show. With sustained attention, the visual representation seems to build up over time. Moreover, after it is built, it stays built in the sense that the dog and the spiral are more rapidly seen on subsequent presentation .

In the case of complex stereograms, the slow development of the percept probably reflects the slow time course of preattentive processing. If the visual representation is the result of preattentive processing plus the current work of attention, then the percept will evolve if the preattentive processes require a significant amount of time to complete their work. There is good evidence for the preattentive processing of disparity information .

It is interesting that these complex stereograms are learned and seen more rapidly on subsequent trials, but this is not directly germane to the claims of inattentional amnesia. Whatever is being learned is somehow stored in a memory that persists for a long time and exists in the absence of the visual stimulus. The learning is not an example of change in the visual representation.

The stereoscopic spiral slowly develops as you look at it. The blob dog example is somewhat different. Subjects either see the dog or they don't see the dog. This does not seem to be an example of a slow preattentive process. Rather, it is a failure of attentive object recognition. This example illustrates the second tenet of the inattentional amnesia hypothesis. At the locus of attention, contact with other cognitive processes can alter the visual representation. On initial exposure, the blob dog fails to make contact with any stored material. Once the subject learns to see the blob dog as a dog, it is seen as a dog. The claim of the inattentional amnesia hypothesis would be that the blobs are seen as a dog only when attended and that the post-attentive representation of the blob dog, like the preattentive representation , is a collection of blobs. Of course, the hypothesis makes the same claim about every object. They are only seen as recognizable objects when attended.

Attention as the bridge to memory

Attention is the pathway around what would otherwise be the crippling effects of inattentional amnesia. The objects of attention reach into memory. The temporal details of the paths from vision to cognition are the subject of a number of chapters in this book. Potter's chapter proposes a "Conceptual Short Term Memory" that is "conceptually structured and tightly linked to long-term memory". It is a bridge between the contents of the visual representation and the stored information that can give meaning to those contents. The chapters on the Attentional Blink (Shapiro and Luck) and Repetition Blindness (Kanwisher) describe some of the limits on this first conceptual stage of processing. When this bridge is blocked or overloaded, stimuli are not remembered. For example, the Joseph et al. (1997) experiment shows that simple feature search cannot be done during the attentional blink. Inattentional amnesia holds that the search stimuli were seen. However, the search task could not be performed until the blink had passed. By that time, it was too late. The stimulus had disappeared into James' "bottomless abyss of oblivion" .

It is interesting to ask how much processing can be done without leaving a usable trace in explicit memory. For example, Luck et al. performed an experiment that is similar in spirit to the Joseph et al. experiment. They presented words during the attentional blink. Like the blinked search task of Joseph et al., the blinked words could not be recalled, but the meanings of those words had an impact on the N400 wave of the ERP. Apparently, the words were read and understood at some level in the system but left no mark in explicit memory.

Blindness or Amnesia?

The Luck et al. result returns us to the difficult task of choosing between inattentional blindness and inattentional amnesia. There are two choices. One can argue that the words in the Luck et al. experiment were not seen but were, nevertheless, processed to a level of word meaning sufficient to produce semantic effects on the ERP. Alternatively, one could argue that the word was seen. It reached something like the Conceptual Short Term Memory described by Potter . This would account for its ability to influence the ERP. However, because of the temporal dynamics of CSTM, the word failed to create a more lasting explicit memory. In this account, the word was seen, fleetingly remembered and then forgotten before it could be reported.

To some extent, this argument rides on the definition of what it means to consciously perceive something. Can one be said to consciously see something if one cannot remember seeing it an instant later? I see no reason why not. If I showed a victim a picture and then subject him to an electroconvulsive shock, he would have no conscious memory of having seen the picture, but it seems wrong to me to assert than he did not have a conscious experience of the picture. Dreams may provide a more benign analogy. We have all had the experience of waking out of a dream and feeling its contents evaporate. Indeed, within moments we may recall nothing more than the feeling that we had a dream. Consider that vision is like a dream. While you a dreaming, attending, or seeing, the products of those processes are all very real and very present to you. However, the moment you are not dreaming, attending, or seeing "These, our actors, ... are melted into air, into thin air ... the baseless fabric of this vision,... this insubstantial pageant faded, leave(s) not a rack behind."

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