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RESEARCH ARTICLE

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Random visual noise impairs object-based attention

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Abstract Object-based visual attention is observed when the benefit of attending to one element in a display extends to other elements that are part of the same perceptual object. Apperceptive agnosia is an object identification deficit in which spatial attention is preserved but object-based attention is impaired. Some debate exists regarding the extent to which the object-based impairment can be attributed to perceptual mechanisms that are specifically involved in grouping and segmentation of a scene, as opposed to early sensory processes. In the present paper we show that random visual noise is sufficient to eliminate the object benefit, a result inconsistent with the view that grouping mechanisms are responsible for the effect. The results have implications for an understanding of apperceptive agnosia, and for an understanding of object-based attention more generally.

Keywords Agnosia · Visual attention · Object recognition · Vision · Perception

Introduction

Because our perceptual abilities are limited, efficient processing of stimuli from our surroundings requires the selection of only a portion of the world for further consideration. In the visual domain, mechanisms of selective attention perform the function of selecting a subset of a scene upon which to focus. Traditional views of the selection process assume that selection is made from a spatial representation such that some elements of a scene are passed along for further processing based on their *position* in the scene (see, for example, Downing and Pinker 1985; Eriksen and Hoffman 1972). Nevertheless, it is becoming increasingly clear that attentional selection may also be made on the basis of the *objects* that are in a scene without regard to their particular spatial location. For example, Duncan (1984) found that subjects were better able to report two attributes from a single object than they were to report one attribute on each of two superimposed objects. That result occurred despite the fact that the spatial separation of the attributes was the same in the one- and two-object situations. Such object-based attention has been the focus of considerable research, in part to understand the nature of the attributes that can or cannot serve as the basis for attentional selection (see, for example, Lamy and Tsal 2000), and also in order to attain a better understanding of the nature of perceptual objects (see, for example, Moore et al. 1998) and of their role in guiding attention (see, for example, Abrams and Law 2000).

Much of our understanding of the role of objects in attention comes from a paradigm introduced by Egly et al. (1994). They had subjects view a display containing two rectangles, as illustrated in Fig. 1. Attention was first attracted to one end of one of the rectangles by a transient cue (the brightening of one rectangle end). After a brief delay, a target was presented in one end of one of the rectangles, and subjects were to press a key when they detected it. Subjects were fastest to detect the target when it appeared in the cued location (as shown in Fig. 1), showing that the subjects had allocated attention to the location of the cue. More interesting are the trials on which the target appeared in an uncued location. On some such trials the target could appear in the uncued end of the object that had been cued (*bottom left* in the example in Fig. 1), but on other trials it appeared in the uncued object (*top right* in the display in Fig. 1). Egly et al. (1994) showed that normal subjects show an on-object benefit: they were faster to detect targets in the uncued end of the cued object compared to targets appearing in the uncued object. The result shows that elements of a scene may be selected for processing because of the objects that they are part of, and not merely due to their spatial location. In the Egly et al. (1994) study the benefits of attention appeared to radiate through the attended object, hence the phenomenon has

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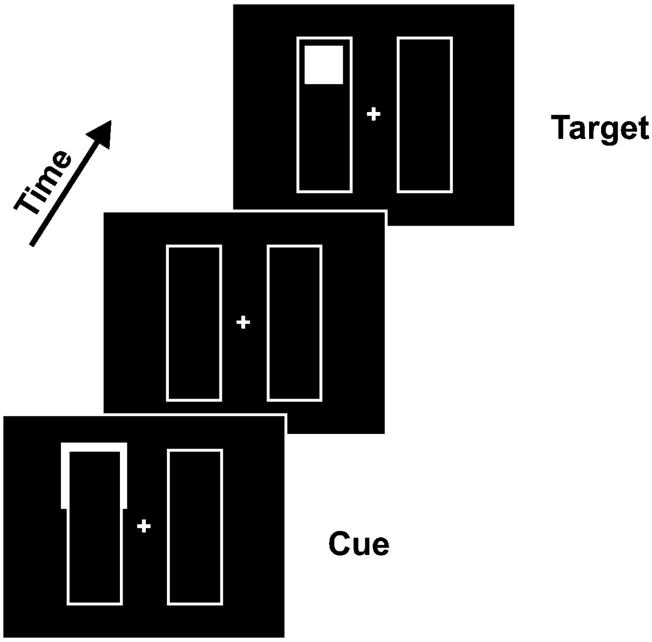

Fig. 1 Experimental paradigm used by Egly et al. (1994). The target could appear in either end of each of the rectangles. Subjects are fastest to detect targets in the cued location (as shown in the example). Targets in the uncued end of the cued rectangle are more quickly detected than those in the uncued rectangle, revealing an object advantage

been called “radiation of attention” by some researchers (Abrams and Law 2000).

One issue of interest to researchers studying object-based attention involves the nature of the processing that precedes recognition of the objects in a scene. For example, Peterson and Gibson (1994) showed that the depiction of a familiar object in a display affected the segmentation of an otherwise ambiguous scene into figure and ground regions. The ability to recognize the object as familiar presumably required access to some sort of long-term memory representation, but the segmentation into figure and ground might be regarded as an early, low-level operation. Hence, the Peterson and Gibson (1994) result suggests a complex, interactive relation between higher and lower processing mechanisms in the visual stream. Results of DiLollo et al. (2000) also are consistent with a richly interactive system in which higher level processes may affect the operation of lower level processes. In their paradigm, subjects were shown a target object and a flanking, masking object. When both target and mask were presented and removed simultaneously, target identification could be accurate. However, if the mask was allowed to remain displayed after target offset, target identification suffered. DiLollo et al. argued that the continued stimulation from the mask became incorporated into the representation that was being formed of the target as a result of reentrant processing in the visual system. According to their model, output from higher-level processes can be reinterpreted when it is considered along with subsequent incoming stimulation.

In the same spirit as the work just discussed, researchers have also been interested in learning more about the nature of the processing needed to give rise to object-based radiation of attention. For example, the finding that attention may radiate through perceived objects (see, for example, Egly et al. 1994) is consistent with the idea that object recognition might be performed on the basis of an early segmentation of a scene, with the perceived objects subsequently affecting the allocation of attention (see, for example, Vecera and Farah 1994; but see Kramer et al. 1997). However, there are a number of ways in which attention may be directed to an element of a scene, so it is reasonable to ask whether all are equally able to generate attentional radiation. In particular, when Egly et al. (1994) studied attentional radiation, they summoned attention to the periphery by a salient event, engaging what is sometimes called *stimulus-driven* attention. But attention can also be moved in a more goal-directed fashion, driven by the goals of the observer. Macquistan (1997) and Abrams and Law (2000) asked whether attention would radiate through an object equally regardless of whether attention had been directed endogenously (by a symbolic cue presented centrally) or exogenously (by a peripheral flash in the location to be attended). Indeed, Macquistan (1997) found that such radiation did *not* occur with goal-directed endogenous attention, suggesting that the processing or segmentation of the objects occurred at some level beyond that upon which goal-directed attentional mechanisms operate. Abrams and Law (2000), however, were unable to replicate Macquistan’s results and instead found evidence for attentional radiation in a range of tasks with both endogenous and exogenous attentional cueing. Their results are more consistent with the view that an early segmentation of a scene into objects precedes the stages at which attentional mechanisms operate. Nevertheless, questions still remain about the relative locus of object recognition and effects of objects on attention.

An alternative approach to understanding object perception involves the study of patients with deficient perceptual abilities, in particular apperceptive agnosics (Farah 1990). Apperceptive agnosics have difficulty perceiving and recognizing objects. The deficit is thought to arise from damage to early visual processes, although there is some question about precisely what processes are damaged. In a task testing for radiation of attention like the one shown in Fig. 1, an apperceptive agnosic was fastest to detect the target when it appeared in the cued location, showing, as do normals, the ability to allocate attention to the location of the cue (Vecera and Behrmann 1997). Importantly, however, the apperceptive agnosic studied by Vecera and Behrmann (1997) did *not* reveal an object advantage; they were equally fast in the two uncued conditions.

The failure of the agnosic to exhibit object-based radiation of attention might provide important insights into the nature of agnosia as well as into the mechanisms that are responsible for object-based attention more generally. But this insight may depend on adjudicating between two competing explanations of agnosia. According to one alternative, apperceptive agnosics essentially view the world through random visual noise (or a "peppery mask"; Campion and Latto 1985). Such a possibility is consistent with observed widespread and random scotomas in apperceptive agnosics (Campion and Latto 1985). An alternative possibility proposes instead that the deficit exhibited by apperceptive agnosics arises specifically from impaired perceptual-grouping mechanisms (Farah 1990; Vecera and Behrman 1997). This possibility is consistent with the observation that agnosics have difficulty grouping together even perceptual elements that are successfully perceived (i.e., elements that were perceived despite any scotomas; Farah 1990).

To help resolve the conflict between theoretical explanations, Vecera and Gilds (1998) attempted to simulate apperceptive agnosia in neurologically intact individuals by using one of two manipulations. With one manipulation, subjects viewed attentional radiation stimuli such as those shown in Fig. 1 through a filter of random noise elements, much like what is suggested by the peppery mask accounts of agnosia. In the other manipulation, subjects viewed stimuli from which elements thought to be crucial for perceptual grouping processes (such as rectangle corners) had been removed. Vecera and Gilds found that the peppery mask manipulation did not successfully simulate the behavior of the agnosic patient, but the other manipulation did. Therefore, Vecera and Gilds concluded that apperceptive agnosia involves a specific deficit in perceptual grouping mechanisms. The result also suggests more generally that mere visual noise is not sufficient to eliminate the information needed for attention to radiate through an object. Instead, some impairment specifically in the ability to group perceived elements together is necessary to produce the deficit.

The Vecera and Gilds (1998) conclusion is consistent with the view that object-based attentional radiation relies upon perceptual processes that are specifically devoted to grouping already-perceived elements into perceptual objects. This is because a random noise mask, presumably affecting earlier perceptual processes, did not disrupt the phenomenon. However, the mask that Vecera and Gilds used was completely ineffective, producing neither a main effect nor an interaction effect in their dependent variable (reaction time). As a result, their test is not a strong one, and the implications of their findings for understanding object-based attention are questionable. In particular, if it can be determined that random visual noise can indeed eliminate object-based attentional radiation, then it might be necessary to reevaluate the supposed role of higher-level grouping mechanisms in the phenomenon.

In the present paper, we report an attempted replication of the crucial portion of the Vecera and Gilds study. However, we used a visual noise mask that was sufficient to produce at least a main effect in the response latencies. The agnosic patient studied by Vecera and Behrmann (1997) revealed an intact ability to allocate attention to the location of the cue, but did not show the typical (in normal subjects) object advantage for targets appearing in uncued locations. That was the particular pattern of results that we (and Vecera and Gilds 1998) sought to reproduce here in normal subjects who viewed the stimuli in the presence of random visual noise.

Materials and methods

Overview of experiment

We presented a version of the Egly et al. (1994) task to each subject. On each trial one of the four rectangle ends was cued by the brief appearance of a white disk in that end. Shortly after the cue had disappeared a target box appeared in one end and subjects pressed a key as soon as they detected the target. The target could appear either at the cued location ("cued"), the uncued end of the cued object ("uncued same-object"), or in the uncued object at the end closest to the cue ("uncued different-object"). On one-half of the trials subjects viewed the stimuli through a visual noise pattern as illustrated in Fig. 2 (*bottom panel*), and on the other half of the trials no masking noise was presented (*top panel*).

Subjects

Ten neurologically normal young adults (mean age 20.4 years) participated in the experiment. Each subject served for one 30-min session and received $10 as payment. The experiment was approved by the Washington University committee that approves research with human subjects. All subjects provided informed consent prior to participation in the experiment.

Apparatus and procedure

The procedure was very similar to that used by Vecera and Gilds (1998), with the primary exception being that we used a denser visual noise mask. On half of the trials subjects viewed a display that contained two rectangles, and a visual noise pattern, as shown in the *bottom panel* of Fig. 2. On the rest of the trials the display was identical except the visual noise was absent (Fig. 2 *top panel*). The noise pattern was produced by randomly illuminating 0.18° squares on the display. Each square within a 14.7° square area at the center of the display was illuminated with a probability of 0.5. The rectangles fit entirely within that area and were 8.12° long by 1.3° wide with a 0.16° border. A different random pattern was computed for each trial. The resulting visual noise is similar to the peppery mask described by Campion and Latto (1985), and similar to the one used by Vecera and Gilds (1998). Our noise mask was fairly dense because we wanted to be sure that the noise had at least a main effect on response latencies.

At the beginning of each trial a display similar to those depicted in Fig. 2 was shown for 1,000 ms. Next, the cue, a white disk of diameter 0.8°, was displayed for 100 ms centered in one end of one of the rectangles. The target was displayed 200 ms after the cue was removed from the display. The target could appear either at the cued location, the uncued end of the cued object, or in the uncued object at the end closest to the cue. Note that the two potential uncued target locations were equidistant from the cued location and from fixation. The target was a gray 0.8° square centered in one end of a rectangle. The target remained visible until either the subject responded or until the 1,000 ms response period elapsed.

The subject's task was to press the spacebar on the computer keyboard as soon as they detected the appearance of the target. On catch trials, in which no target was presented, subjects were instructed not to make a response. At the end of the trial a blank screen was displayed for 1,000 ms and then the next trial began. Subjects were provided with performance feedback and an opportunity to take a short rest after every 48 trials.

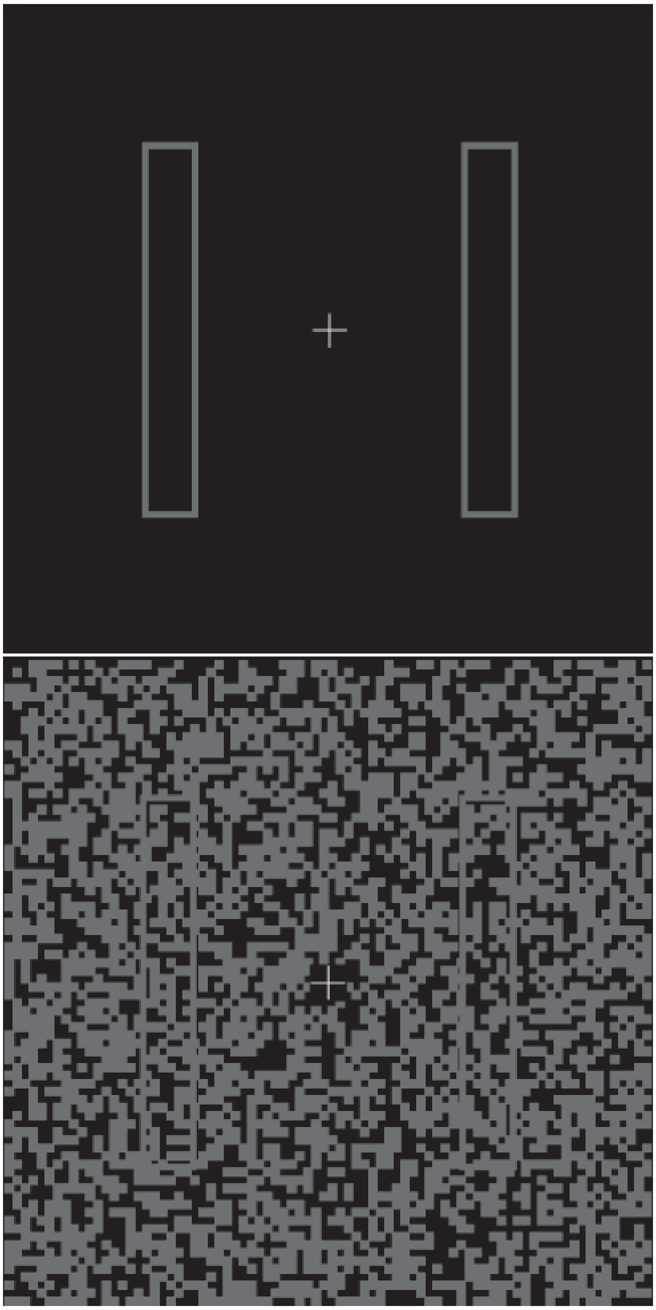

Fig. 2 Examples of the stimuli used in the present experiment. *Top panel* Unmasked condition. *Bottom panel* Masked condition. For the actual stimuli presented during the experiment, the objects were clearly visible in both conditions

Design

At the beginning of each session a practice block of 20 trials was presented, and these trials were randomly selected from among the possible conditions. Four experimental blocks each comprised of 160 trials followed the practice block. Of these 160 trials, 32 (20%) were catch trials on which no target was presented. Of the trials that had targets, 96 were cued, 16 were uncued same-object trials, and 16 were uncued different-object trials. Therefore, of the trials with targets the cue accurately predicted the location of the target 75% of the time. Within each block each condition had an equal number of masked and unmasked trials. One half of the trials in each condition used rectangles that were oriented vertically, as in Fig. 2; the other trials had horizontally oriented rectangles. The order of trials within a block was random.

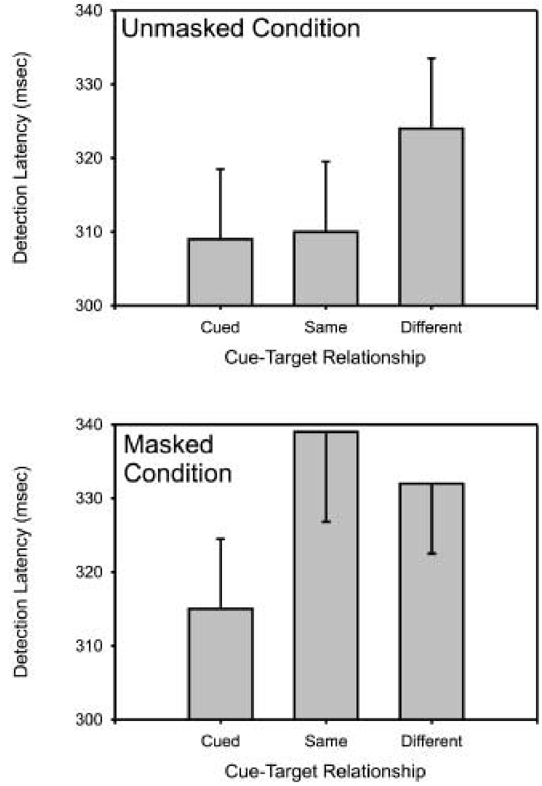

Fig. 3 Mean reaction times in each condition shown separately for unmasked and masked conditions

Results

Mean reaction times in each condition are shown in Fig. 3. First note that we succeeded in producing a mask that yielded a main effect: subjects were slower when the visual noise mask was present (mean 328 ms) than when it was absent [mean 314 ms; $F(1,9)=16.8$, $P<0.005$]. Next, consider the cueing condition. There was an overall main effect of cueing condition [$F(2,18)=7.9$, $P<0.005$]. Subjects were fastest in the cued condition (mean 312 ms), slower in the uncued same object (mean 325 ms), and slowest in the uncued different object condition (mean 328 ms). However, the effects of cueing condition interacted with those of the mask [$F(2,18)=7.0$, $P<0.01$]. As seen in the figure, there was a cuing benefit for both masked and unmasked conditions. Furthermore, there was an object benefit in the unmasked condition (mean object benefit 14 ms): subjects were nearly as fast to respond to targets in the uncued same-object condition as in the cued condition, but they were much slower in the uncued different-object condition. However, there was no object benefit at all in the masked conditions (mean object benefit –7 ms). Subjects there were actually somewhat slower (but not significantly so) to detect the target when it appeared in the uncued same-object condition relative to the uncued different-object condition.

Error rates were less than 4.5%, and no further analysis of errors was performed.

As a control, we performed an additional experiment to confirm that the subjects could easily see the rectangular objects in the conditions containing a mask. We had a group of ten undergraduates view masked rectangles identical to the ones used in the experiment reported. These subjects were asked to indicate the direction (horizontal or vertical) in which the rectangles were oriented, and to do so with the same time constraints as in the original experiment. Subjects were correct in identifying the orientation on 96% of the trials, indicating that there was enough information available in the image for perception of the objects.

Discussion

In the present study we showed that a random visual noise mask is sufficient to eliminate object-based radiation of attention and to produce the pattern of results that Vecera and Behrmann (1997) reported for an apperceptive agnosia patient. In particular, here both with and without the noise mask, subjects were fastest to respond to targets appearing at the cued location. This is consistent with the observation that both normals and apperceptive agnosia patients are capable of allocating attention to a cue. However, an object advantage was observed only in the conditions without the visual noise mask. Thus the random visual noise was sufficient to eliminate the object advantage in visual attention, and hence was successful in simulating one symptom of apperceptive agnosia in our neurologically normal subjects.

The present results have implications for the nature of the processing that underlies object-based radiation of attention. In particular, they suggest that radiation of attention may require the successful segmentation of a scene into objects early in visual processing. This is because random noise was sufficient to eliminate the object-based effect, and it was not necessary to remove specific key elements of the objects, as Vecera and Gilds (1998) had concluded. Importantly, we obtained the object-based impairment in the presence of an intact ability to identify the objects that were present, so higher level processes were indeed capable of segmenting the scene correctly. That pattern suggests that the segmentation that is accessible for conscious report may differ from the representation that is operated upon by attentional mechanisms.

Our results also have important implications for an understanding of agnosia. Because the random visual noise was capable of simulating agnosia, our results suggest that absence of an object advantage in apperceptive agnosia need not arise from damage to object grouping process per se. Instead, it is possible that the object-based deficit arises from the need for these patients to view the world in the presence of multiple, randomly located scotomas, as if through a peppery mask.[1]

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[1] It is important to note that we are not arguing that apperceptive agnosia patients necessarily have intact object grouping process. Instead we have shown that random visual noise is sufficient to produce the effect in normals that Vecera and Gilds (1998) attributed to a grouping deficit. Thus, if random noise eliminates the object advantage, the absence of an object advantage cannot be taken as evidence for impaired perceptual grouping mechanisms. Indeed, Vecera and Gilds (1998) describe a number of additional observations regarding agnosia that appear more consistent with a grouping deficit explanation than with a peppery mask.