Research Report

Amodal Completion in Visual Search

Preemption or Context Effects?

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ABSTRACT—***In a previous study, search for a notched-disk target abutting a square among complete-disk nontargets and squares was inefficient in 250-ms exposures, but relatively efficient in 100-ms exposures. This finding was interpreted as evidence that amodal completion proceeds through a mosaic and then a completion stage, with the latter preempting the former. We used the same target but changed its context: Nontargets were instead notched disks near squares. Task set was also different: Participants searched for a complete disk. Contrary to the prediction of the preemption model, search was efficient in the 100-ms condition and inefficient in the 250-ms condition. We propose that in both the present and the previous studies, the target was ambiguous, and task set and context affected how it was perceived. In both experiments, set effects were evident for 100-ms exposures; context effects were evident for 250-ms exposures.***

In a study by Rauschenberger and Yantis (2001), participants searched for a notched disk among complete disks and squares. In one condition (*adjacent* target), the notched-disk target was adjacent to one of the squares, such that it shared a portion of the border of the square. Consequently, the notched disk became a candidate for amodal completion. In another condition (*separate* target), the notched disk was separated from its companion square and, hence, was not a candidate for completion (see Fig. 1). Displays were masked after either 100 or 250 ms. Rauschenberger and Yantis found that at the 250-ms exposure, search was efficient for the separate notched-disk target, whereas search for the adjacent notched-disk target was inefficient (cf. Rensink & Enns, 1998). Search for the separate target remained efficient at the 100-ms exposure, and search for the adjacent target became efficient. Rauschenberger and Yantis argued that the pattern of results they obtained was consistent with a two-stage model of amodal completion (TSM; Sekuler & Palmer, 1992) in which the adjacent target is represented first as a notched disk (dissimilar to the nontargets) and later as a complete disk (similar to the nontargets).

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Central to the TSM is the idea that the completed representation preempts the notched representation, and that the final representation is unambiguously that of a complete surface partially occluded by another (Sekuler & Palmer, 1992). There is an alternative to the preemption view, however, and that is that a notched disk adjacent to a square is ambiguous, open to interpretation as either a mosaic pattern or a disk occluded by a square. In a study consistent with this alternative view, Peterson and Hochberg (1983) showed that the observer's perceptual set could influence whether the mosaic pattern or the occluded disk was perceived. Furthermore, Gerbino and Salmaso (1987), Bruno and Gerbino (1987), and Gerbino (1989) suggested that concurrently achieved completion and mosaic interpretations of line drawings may be disambiguated by context (which they inferred from visual matching data, but otherwise did not test directly). More recently, Bruno, Bertamini, and Domini (1997) pointed out that two-dimensional displays such as those used by Rauschenberger and Yantis (2001) confront the visual system with conflicting information: Whereas local features such as T-junctions suggest a complete interpretation, other sources of depth information, such as binocular disparity, motion parallax, and accommodation, support the mosaic interpretation. Consequently, Bruno et al. argued, it is likely that the visual system entertains both interpretations.

The ambiguity account does not require that the occluded-disk interpretation be available as early in time as the mosaic pattern. Indeed, a substantial amount of evidence shows that it takes time to generate a complete-disk representation for a two-dimensional display containing a notched disk abutting a square (Guttman, Sekuler, & Kellman, 2003). However, contrary to the TSM, the ambiguity account abandons the requirement that the complete-disk representation replace the notched-disk representation. Rather, once the completed representation becomes available, both the mosaic and the completed representations are available. Extrinsic factors then determine which interpretation prevails.

Can the pattern of results Rauschenberger and Yantis (2001) obtained in the 100-ms and 250-ms conditions be interpreted as consistent with the view that the adjacent target is ambiguous? Consider the 100-ms condition first: Although the complete-disk representation may have become available as an alternative to the notched-disk representation, the participants' task set ("find a notched disk") may have biased the

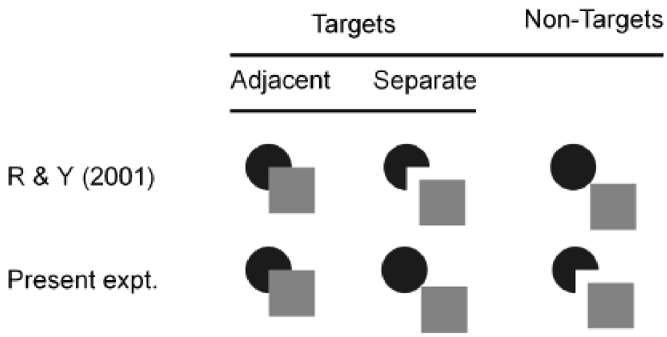

Fig. 1. Illustration of the stimuli used by Rauschenberger and Yantis (2001) and in the present experiment. In Rauschenberger and Yantis (R & Y), the target stimulus was either a notched disk abutting a square or a notched disk standing separate from the square; nontargets were complete disks and squares. In the present study, the target stimulus was either a notched disk abutting a square (*adjacent* condition) or a complete disk near a square (*separate* condition); nontargets were notched disks and squares.

ambiguous target toward the notched-disk interpretation (cf. Humphreys & Müller, 2000). The target was therefore perceptually distinct from the complete-disk nontargets, and search was efficient. Consider the 250-ms condition next. The completed representation was presumably available on most trials. The top-down bias toward the notched disk persisted, but may have been superceded by *spatial context effects*, as follows. In Rauschenberger and Yantis's search displays, the nontargets were all complete disks. It is possible that the nontargets constituted context elements that biased the perception of the target toward its complete-disk interpretation, thereby rendering search inefficient.

Previous research showed that the global shape of a notched object itself can affect which of two possible completions will be perceived (Sekuler, 1994; van Lier, Leeuwenberg, & van der Helm, 1995), and that past experience can affect whether or not completion is perceived (Joseph & Nakayama, 1999; Zemel, Behrmann, Mozer, & Bavelier, 2002). In this earlier work, however, it was assumed that one or the other completed interpretation necessarily preempted the fragmented interpretation. Here, we suggest that search became inefficient in Rauschenberger and Yantis's (2001) 250-ms condition not because of a ballistic two-stage completion process, but because of the bias exerted by the complete-disk nontargets. Because these context effects operate between spatially distributed items, they require time to affect the target. In sufficiently short displays, context effects are therefore either attenuated or absent, allowing the participants' search set to determine the dominant representation of the target. Such top-down effects have an extremely short time course because the biasing information is already in the system before the afferent information from the display ever arrives.

To distinguish between the ambiguity account and the TSM, we changed Rauschenberger and Yantis's (2001) design in two important ways (see Fig. 1). First, we changed the nontargets from complete disks near squares to notched disks near squares. Second, we instructed participants to search for a complete disk, rather than for a notched disk. The target in the *adjacent* condition was the same as that used by Rauschenberger and Yantis. The target in the *separate* condition was changed from a notched disk to a complete disk. According to both the TSM and the ambiguity account, the separate condition should produce efficient search, regardless of the exposure duration. Following Rauschenberger and Yantis, we use the separate condition as a point of reference when interpreting the results obtained in the adjacent condition at the different exposure durations.[1]

The TSM and the ambiguity account make radically different predictions under these different conditions. According to the TSM, search for the complete disk should be inefficient in the adjacent condition at the 100-ms exposure because amodal completion has not yet had a chance to render the target sufficiently dissimilar to the notched disk nontargets. Thus, for 100-ms displays, search slopes should be significantly steeper in the adjacent condition than in the separate condition. Furthermore, search should be efficient at the 250-ms exposure for both the adjacent and the separate conditions because amodal completion renders the adjacent notched disk dissimilar to the notched-disk nontargets. Thus, the TSM predicts that the results in this task will be the converse of those reported by Rauschenberger and Yantis (2001).

The ambiguity account, by contrast, predicts that the results will be the same as Rauschenberger and Yantis's (2001). In the 100-ms condition, search should be efficient not only for separate targets, but also for adjacent targets, because in the adjacent condition, task set should bias perception toward the completed interpretation of the target—at least on those trials on which completion has been accomplished. Search should remain relatively efficient for separate targets in the 250-ms condition, whereas it should be inefficient for adjacent targets in this condition because the context of notched-disk nontargets should bias the perception of the adjacent target toward the notched-disk interpretation. By contrast, context should have little effect on the perception of the target in the separate condition. Although the displays used in the present experiment differ from those used by Rauschenberger and Yantis, the underlying mechanisms are the same; hence, the pattern of results should be similar.

METHOD

Thirteen participants searched for a "complete disk" among notched disks. As in the study by Rauschenberger and Yantis (2001), error rate was the dependent variable. The target was either a complete disk touching one of the vertices of a square (*separate* condition) or a three-quarter notched disk with a square nestled into the notch (*adjacent* condition). Displays contained either two, four, six, or eight disk-square pairs.[2] All other methods followed those of Rauschenberger and Yantis (2001).

RESULTS

The results for target-present trials are shown in Figure 2. (Target-absent data are shown separately in Fig. 3.[3]) As the ambiguity account

[1]The relative increase in search efficiency predicted for the adjacent target in the 100-ms condition can be revealed only by comparison with search efficiency in the separate condition, because any effects attributable purely to the shorter exposure duration operate in both conditions.

[2]After data collection, we realized that "search" efficiency was vastly underestimated with a set size of two because when there are only two display items, the task becomes a same/different task rather than a search task. Five different experiments using briefly exposed stimuli like those employed here all evidenced an anomaly at this set size. On the basis of those experiments, we decided to exclude results for the set size of two from further analysis.

[3]Target-absent trials are not interesting for our purposes because, on these trials, there is no target present to be influenced by the nontargets.

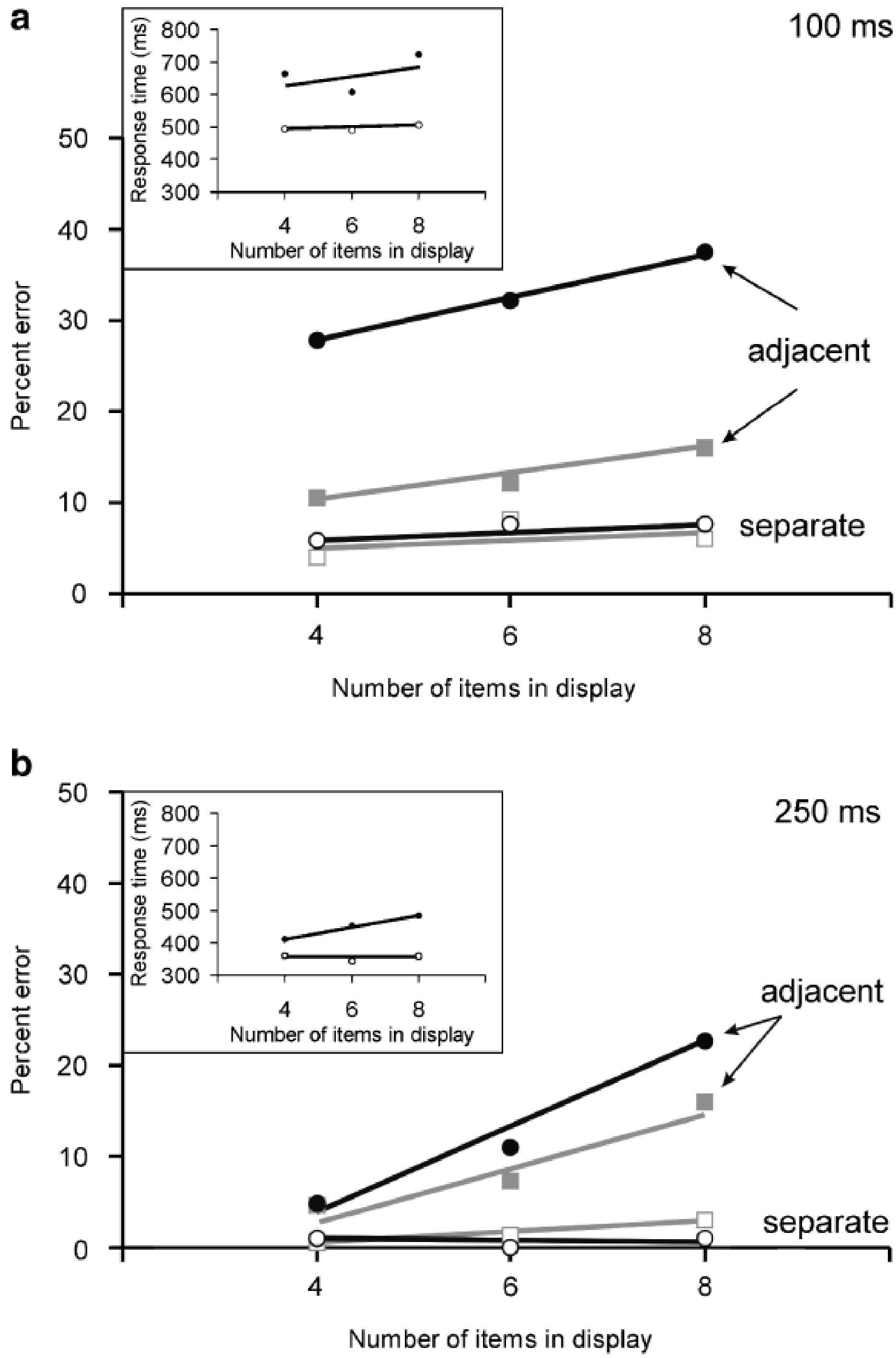

Fig. 2. Percentage of errors in target-present trials at the 100-ms (a) and 250-ms (b) exposures. Participants' performance, plotted in black, is shown separately for the two target types (adjacent—closed symbols, separate—open symbols) as a function of the number of items in the display. The insets show response times. The error data from Rauschenberger and Yantis (2001) are plotted in gray, permitting a direct comparison of the two studies.

predicted, search was comparably efficient for adjacent and separate targets in the 100-ms condition (see Fig. 2a), $F(2, 24) = 1.7$, n.s.; according to the TSM, the representation of the adjacent target should have been incomplete in this condition and hence visually similar to the nontargets, producing inefficient search. In the 250-ms condition, search was inefficient for adjacent targets relative to separate targets (see Fig. 2b), $F(2, 24) = 28.1$, $p < .001$; according to the TSM, amodal completion should have rendered the adjacent target visually distinct from the notched-disk nontargets in this condition, producing efficient search. To emphasize just how similar our pattern of results is to

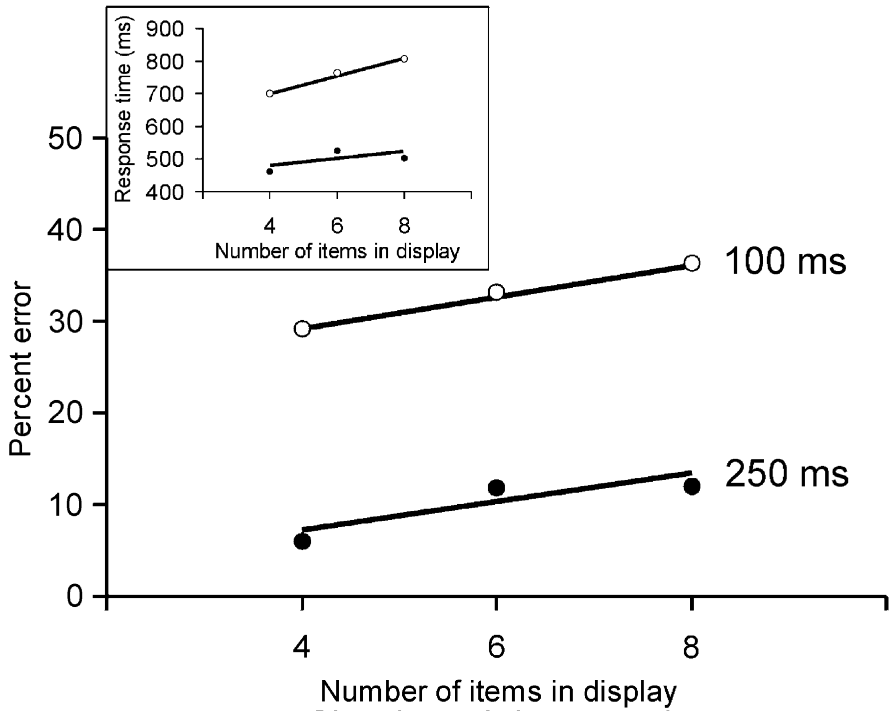

Fig. 3. Percentage of errors on target-absent trials as a function of number of items in the display. Closed symbols represent the 250-ms condition, open symbols the 100-ms condition. The inset shows response times in the two conditions.

Rauschenberger and Yantis's (2001), we plotted their results with light gray lines in Figure 2, where it can readily be seen that the two studies indeed share a very similar pattern of data. The only difference is seen in the 100-ms adjacent condition.

In this condition, there were more errors in the adjacent condition than in the separate condition, $F(1, 12) = 54.0$, $p < .001$. This effect is larger than similar effects reported previously (Rensink & Enns, 1998), and may be explained by the occasionally slow time course of amodal completion. If completion did not proceed sufficiently before the display was masked, the display was effectively represented as a target-absent display because all the display items (including the target) were represented as notched disks. In Rauschenberger and Yantis's study (2001), an unavailability of the completed representation accorded with the participants' task, but in the present study, it conflicted with it. It is important to note that the errors made in the 100-ms condition were not systematically related to the number of nontargets: Search remained efficient, a result consistent with the interpretation that, when present (and amodal completion had succeeded), the target was perceptually dissimilar to the nontargets.

The comparable search efficiency for adjacent and separate targets in the 100-ms condition was not due to a ceiling effect in the adjacent condition. The error rate for a set size of eight differed significantly from 50%, $t(12) = 2.18$, $p = .01$, two-tailed. Moreover, for a proper comparison with chance, "no target" responses on both target-present and target-absent trials must be averaged. Those means—30%, 32%, and 35% (for set sizes of four, six, and eight, respectively, in the 100-ms adjacent condition)—are well below 50%, $ps < .0005$. As in Rauschenberger and Yantis (2001), the comparability of search efficiency in the adjacent and separate conditions was also not due to the fact that performance in the separate condition deteriorated to the level of performance in the adjacent condition. The slopes for the separate target were indistinguishable in the 100-ms and the 250-ms conditions, $F < 1$.

As in Rauschenberger and Yantis (2001), response times corroborate the effects observed in the error data (see Fig. 2, insets): In the 250-ms condition, search was significantly less efficient for adjacent targets than for separate targets, $F(2, 24) = 5.0$, $p < .05$, whereas in the 100-ms condition, search efficiency was equivalent for the two target types, $F(2, 24) = 1.2$, n.s. Further corroboration comes from a replication of our experiment with 14 new observers. In this replication, the complete disk in the separate condition overlapped the square with which it was paired, so that the diagonal extent of the separate target was equated to that of the adjacent target. As before, the adjacent target yielded less efficient search than the separate target at 250-ms exposures, $F(2, 13) = 9.17$, $p < .01$, but there was no such difference in search efficiency at 100-ms exposures ($F < 1$). The smaller diagonal extent of the adjacent target relative to the separate target therefore cannot account for our results.

DISCUSSION

Our results are quite incompatible with the TSM: Although TSM advocates might propose that completion operates more quickly than 100 ms, explaining the relatively efficient search at the short exposure, search should have been efficient at 250 ms as well in that case. Similarly, although one might suggest that search was inefficient at the long exposure because completion was delayed past 250 ms by the context of notched disks, it should certainly have been delayed past 100 ms in that case, and search should have been inefficient at both exposure durations.

Our results are the first to show that nontargets can provide a context that affects the interpretation of a visual search target. Previous studies have suggested that perceptual interactions between the target and the nontargets may give rise to emergent properties in search displays (e.g., Banks & Prinzmetal, 1976; Pomerantz, Seger, & Stoever, 1977). In these studies, search was facilitated or impeded by configurations spontaneously emerging from relations between the display items, but the perceptual organization of the target was typically assumed to remain unaffected by the nontargets.

It is conceivable that the type of context effect described here operates in other visual search displays as well. This speculation is consistent with a model proposed by Rauschenberger and Yantis (2003). According to this model, when the target is outnumbered by nontargets, the visual system may overgeneralize from the nontargets to the target. Context effects may constitute one example of such overgeneralization. What surfaces in our experiment as a performance impediment may have adaptive value under other circumstances: Generalizing across a largely homogeneous display may be an economical encoding mechanism.

The spatial context effects described here must be distinguished from another class of visual search findings, first reported by Chun and Jiang (1998), that are likewise referred to as context effects. Chun and Jiang showed that when targets were repeatedly presented in the same location in the same spatial arrangement as nontargets, participants' response times to find the targets decreased over presentations. The facilitation observed by Chun and Jiang constitutes implicit memory for display configuration, whereas the context effects described here are a perceptual phenomenon. The former requires several trials to accrue; the latter are generated on-line, in real time. Finally, the implicit learning reported by Chun and Jiang does not affect the actual representation of the target, whereas the very essence of the effects demonstrated here is that the other items in the display modify the representation of the (ambiguous) target stimulus.

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