

How Are Different Properties of a Scene Encoded in Visual Memory?

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Recent studies in scene perception suggest that much of what observers believe they see is not retained in visual memory. Depending on the roles they play in organizing the perception of a scene, different visual properties may require different amounts of attention to be incorporated into a mental representation of the scene. The goal of this study was to compare how three visual properties of scenes, colour, object position, and object presence, are encoded in visual memory. We used a variation on the change detection “flicker” task and measured the time to detect scene changes when: (1) a cue was provided regarding the type of change; and, (2) no cue was provided. We hypothesized that cueing would enhance the processing of visual properties that require more attention to be encoded into scene representations, whereas cueing would not have an effect for properties that are readily or automatically encoded in visual memory. In Experiment 1, we found that there was a cueing advantage for colour changes, but not for position or presence changes. In Experiment 2, we found the same cueing effect regardless of whether the colour change altered the configuration of the scene or not. These results are consistent with the idea that properties that typically help determine the configuration of the scene, for example, position and presence, are better encoded in scene representations than are surface properties such as colour.

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Renewed interest in scene perception has been motivated by the idea that very little of what we see is actually retained in visual memory (McConkie & Currie, 1996; Rensink, O'Regan, & Clark, 1997; Simons, 1996; for a review see Simons & Levin, 1997). This view of scene perception raises the question of which properties of a scene end up being represented. This was one of the issues addressed in Rensink et al.'s (1997) study using the "flicker paradigm" in which subjects attempt to detect a change in one element of a scene. Changes always occurred across a visual disruption—a blank gray screen—a manipulation that rendered change detection surprisingly difficult. The critical assumption behind this paradigm is that the intervening disruption delocalizes the visual transient usually produced by the change. Without this transient, there is no perceived visual event at the location of change to attract attention. Rensink et al. (1997) found that detecting changes in items of marginal interest was particularly difficult as compared to detecting changes in items of central interest. Based on these results, Rensink et al. (1997) concluded that focused attention is critical for establishing specific scene elements in memory. However, beyond the fact that items of high semantic diagnosticity—items of central interest—capture attention (e.g. a swimmer in a beach scene), there remains the question of how attention is allocated to purely *visual properties* of a scene (e.g. something without a conceptual valence associated with it). In the study presented here we used the flicker paradigm to address this issue.

One rough sketch of how the perception of a scene might proceed is as follows. During the first glance of a scene the viewer automatically extracts information which contributes to the overall configuration or layout of the scene (Biederman, 1981; Metzger & Antes, 1983). This typically includes imprecise or low frequency properties of larger scale objects which set the context, thereby providing rapid access to the main gist or category of the scene (Schyns & Oliva, 1994). For example, in a street scene larger elements would include the road and the rows of buildings situated on either side. Refining what is known about a scene requires the allocation of additional attentional resources. This increased effort is necessary because details of a scene are contained in smaller scale objects and surface properties—in our street scene such elements might include the markings on the buildings and road.

A two-stage process for scene perception leads to the possibility that properties of objects relevant to the scene layout are processed automatically, that is, without the need for the allocation of attention. In contrast, detail properties are, due to greater processing demands, processed only through focused attention. Our goal was to test this conjecture by manipulating properties that are all likely to be important to scene perception, but that may play different roles within this process (in this paper the properties of colour, position, and presence/absence in scenes were manipulated—the same properties used in Rensink et al.'s study).

Consider that early object or scene representations are typically thought to be shape-based (i.e. edges, contours, parts, and the relations between them; Marr, 1982). Treisman (1985), for instance, proposed that a “primal sketch” is constructed preattentively showing the boundaries formed by various properties within the scene. These boundaries separate, for example, differently shaped patches of uniform colours or textures on surfaces. Changing the spatial relations of these patches by moving or replacing them changes the configuration of the scene. Changing the surface colours or textures, however, does not generally alter what objects are found within the scene or the spatial configuration of the scene. Thus, visual properties that affect the number of elements within the scene or the relations between such elements, such as position or presence/absence, are generally regarded as *configural* properties. In contrast, visual properties of surfaces, such as colour, are generally regarded as holding a secondary role in object or scene recognition. That is, *surface* properties are considered primary only when shape and relational information is not sufficiently informative for fast identification of an object or scene or when surface properties are particularly diagnostic in identifying objects such as fruits or animals (Biederman & Ju, 1988; Price & Humphreys, 1989). Thus, we predicted that colour, a surface property, would not be encoded as readily as position and presence/absence, both configural properties. In other words, colour information would be expected to be less stable in scene representations than either position or presence/absence information.

Because our goal was to assess how attention modulates the encoding of different properties in visual memory, we chose to introduce changes in objects that are *less likely* to draw attention automatically, that is objects of marginal interest. Objects of marginal interest were chosen according to the same criteria used in Rensink et al.’s study (1997). In that study changes to objects of central interest such as people, animals, or vehicles, that is objects that “told the story” of the scene, were detected more readily than changes to other objects in the scene (e.g. trees, buildings, etc.). Detection times for any types of changes made to central interest objects were very fast and did not differ from each other. In other words, visual properties of objects of central interest were relatively well encoded and, thus, due to ceiling encoding effects, did not exhibit differences in change detection. On the other hand, detection times for changes made to marginal interest objects were slower and depended on the types of changes that were made; colour, position, or presence/absence. Thus, manipulations in objects of marginal interest provide an opportunity to assess the relative saliency of different visual properties within the scene representation. In particular, we expected that visual properties that are more likely to be encoded in scene representations have a higher probability of being preserved across flicker.

To assess the stability of colour, position, and presence/absence in scene memory we used a variation of the flicker paradigm. In Rensink et al.’s (1997)

experiments the task was to search for a change in one of these three properties, but subjects were not informed as to *which type* of change would occur on each trial (a manipulation we replicated as part of Experiment 1). In our variation on this procedure subjects were cued with the particular type of change that would occur. Cueing allowed subjects to narrow their attention, focusing only on the single scene property relevant to detecting the change. In the case of properties that are readily encoded in memory, increased attentional resources should not do much to alter their encoding. In contrast, because of the benefits associated with increased attentional resources, cueing might lead to better detection for properties that are generally not automatically encoded. Thus, we predicted that colour change detection (a less salient *surface* property) would benefit more from cueing than would either position or presence/absence change detection (a more salient *configural* property). At the same time, we should emphasize that we cannot make any predictions about the *absolute* times needed to detect changes across different properties. In particular, different properties are presumably processed by different perceptual mechanisms during the early stages of vision (Ungerleider & Mishkin, 1982). Timing differences in the early stages processing do not necessarily have a bearing upon the way that properties are treated at a higher level, for example in visual memory, when they are incorporated into a representation of the scene.

Although we are assuming that a cue for a single property will help subjects to attend to only that property, it is also possible that cueing could influence detection performance for the three properties in different ways. For instance, it is possible that colour, position, or presence/absence detection could be facilitated by cueing because subjects can then focus only a single type of feature. On the other hand, it might be argued that colour changes are qualitatively different from position and presence changes in that it may be impossible to search for such properties without combining them with other object features (Treisman & Gelade, 1980). However, for purposes of our study we are assuming that all three properties, colour, position, and presence/absence, can be processed individually, apart from other properties belonging to the different objects in a scene. Supporting this claim, there are numerous cases where presence/absence of items in a scene has been the focus of search tasks. Treisman's (1985) use of arrays of Qs and Os among which subjects searched for the presence or absence of a small tail on a circle is just one such example. Likewise it has been suggested that object position can be processed separately from other features such as colour and shape (Bundesen, 1990; van der Heijden, de Lange, de Leeuw, & van der Geest, 1996). In our study position changes involve objects shifting positions within the same local region of a scene. Therefore, one can view the our task as detecting the differences in spatial relations between the target object and its local surroundings, *without* having to process other features that may belong to that object.

EXPERIMENT 1

Methods

Subjects. Subjects were members of the Brown University community who participated for course credit or pay. There were 22 subjects in the Uncued condition (1 had to be omitted from analyses due to technical errors) and 22 subjects in the Cued condition (3 had to be omitted from analyses due to technical errors). No subject ran in more than one condition.

Materials. Stimuli were 41 colour pictures of real scenes plus 3 scenes used for practice only, presented in 8-bit colour mode on an Apple 17" colour monitor (832 × 624; 72 dpi). These pictures were collected from the PhotoDisc CD Sampler (PhotoDisc, Inc., Seattle, WA). Pictures were selected for their possession of an object or group of objects which could be easily altered in colour, position, and presence/absence so that the changed versions would look as natural as the original versions. The image sizes were 17.8 × 11.9 cm, 14.0 × 14.0 cm, or 11.4 × 17.0 cm. For each type of change two versions of each scene (A and B) were created using Photoshop (Adobe Systems Inc., San Jose, CA)—these two versions differed only by a single visual property of one object or of one region. Thus, for a given scene there were a total of six versions: Two for each of the three change types.

Design and Procedure. A particular scene was not shown to a subject more than once. Thus, although the subjects viewed every scene in the stimulus set, each scene was only shown with one change type per subject.

Subjects were seated approximately 61 cm from the computer screen. Scenes were presented using RSVP software (Williams & Tarr, 1998) which controlled the display durations and collected response times. They were presented in the repeating sequence: A, A, B, B, ... thereby decoupling change onsets from display onsets (see Fig. 1). A blank gray field was presented between each display, creating a "flicker" (Rensink et al., 1997). The sequence was repeated until the subject responded. The durations of each scene display and blank field were 240 msec and 80 msec, respectively. The same durations were used by Rensink et al. (1997)—their logic was that 80 ms corresponds to the average length of a saccade and 240 msec was empirically determined to be sufficient time to perceive the scene.

Subjects were run in one of two cueing conditions. In the Uncued condition subjects were simply warned that the flicker sequence was about to begin—no information about the type of change was provided, although subjects did know that the change would involve either colour, position, or presence/absence changes. In the Cued condition subjects were first presented with a written cue informing them what type of change to expect in the subsequent flicker sequence: the words "colour", "location", or "appearance/disappearance"

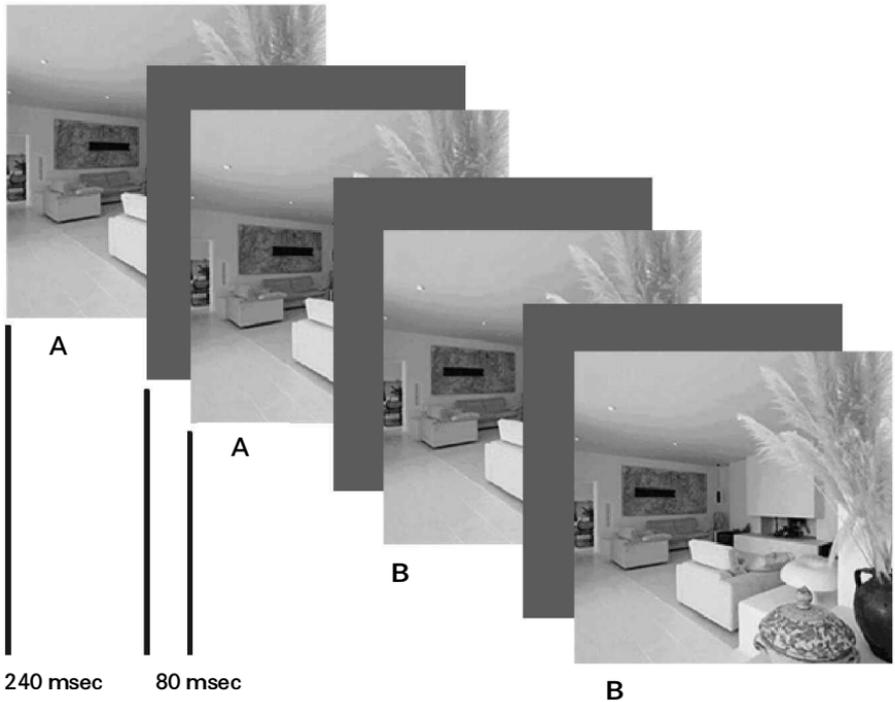


FIG. 1. An example of a trial from the “flicker paradigm” (Rensink et al., 1997). In this example, the change is a position change—the horizontal bar in the picture hanging on the far wall moves from right to left.

appeared on the screen for 500 msec. These cues were followed by the same flicker sequences shown in the Uncued condition. In both conditions the type of cue and the particular change were randomly chosen on a trial-by-trial basis with the restriction that an approximately equal number of each change type was shown across the entire experiment—14 of two change types and 13 of the remaining change type (which type this was varied between subjects) and 41 total trials (not including the 3 practice trials). In both conditions subjects were instructed to view the flickering scene and attempt to locate the change as quickly as possible. As soon they believed that they had detected the change they pressed a key, after which they briefly described or pointed to the changed object. Trials were divided into three blocks, between which subjects were given a brief rest. Subjects were given a chance to view each flicker sequence for a maximum of 38.4 sec (60 alternations) after which the scene disappeared.

Results and Discussion

Trials where the subject failed to detect the change within the allotted time, trials where incorrect changes were reported, and trials where a response was

made without detecting a change were discarded. In the Uncued condition 14.6% of the colour trials, 20% of the position trials, and 7.5% of the presence/absence trials were excluded. In the Cued condition 7.5% of the colour trials, 20% of the position trials, and 9.7% of the presence/absence trials were excluded. Note that the only obvious difference between the cueing conditions occurred for colour trials, the only type of trial affected by cueing in terms of detection times. Indeed, the difference between Cued and Uncued colour trials is in the same direction as the difference in detection times—poorer performance for the Uncued as compared to the Cued condition. The vast majority of these were cases where subjects did not detect the change within the allotted time (in the Cued condition 9 of the colour trials, 41 of the position trials, and 29 of the presence/absence trials; in the Uncued condition 38 of the colour trials, 45 of the position trials, and 27 of the presence/absence trials). Rather than removing outliers, remaining response times were converted to $\log(\text{RT})$ and then averaged for each subject. Overall $\log(\text{RT})$ means were then computed across subjects and the inverse \log was taken to yield geometric means for each condition.

Two-sample (with subjects as the random factor) and matched-pair (with scenes as the random factor) t -tests were then used to compare the means for each change type between the Cued and the Uncued conditions. Out of the three types of changes only colour changes were detected faster in the Cued condition than in the Uncued condition: colour, $t(38) = 3.69$, $p < .001$, position and presence/absence both $t < 1$ (Fig. 2). When the detection times were analyzed using scenes as the random factor we obtained the same pattern of results: colour, $t(40) = 5.93$, $p < .001$, position and presence/absence both $t < 1$.¹

In short, only colour change detection times were facilitated when cues were provided. Within the framework presented previously, these results suggest that colour information is less salient in short-term visual memory. In contrast, the detection of changes in position or presence/absence information was not facilitated by cueing. Such results are consistent with the idea that properties of surfaces such as colour are not as readily encoded as configural properties such as position or presence. If the effect of cueing results from the configural/non-configural distinction between scene properties then perhaps this effect may be eliminated by rendering colour more salient in initial representations of the scene. One possible method for making colour more salient might involve colour changes that produce configural changes in the layout of the scene. For example, if two adjacent walls were differently coloured they would most likely be segmented into separate regions, but if they were the same colour, they might be grouped together into a single region. Thus, colour changes can produce changes to the perceived configuration of a scene—

¹Note that the Cued/Uncued manipulation is between subjects, but within scenes.

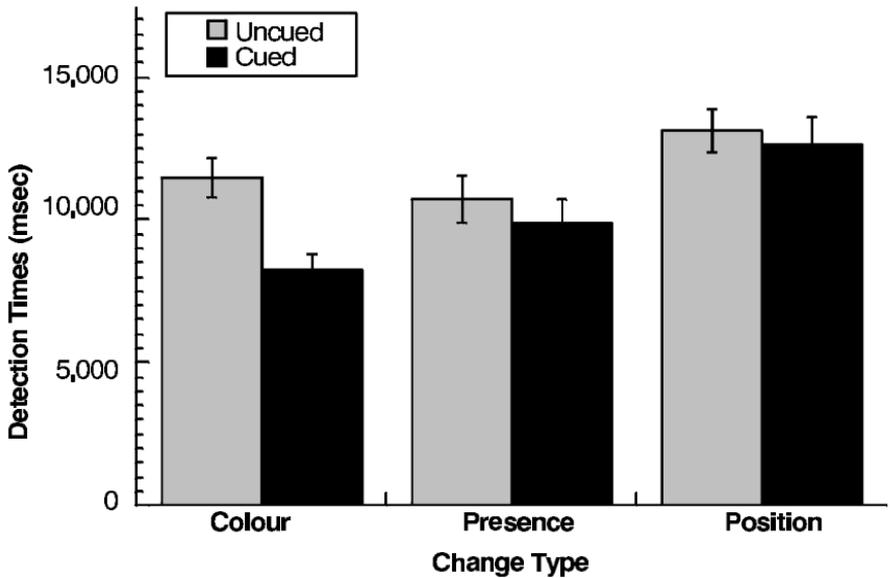


FIG. 2. Experiment 1. Mean change detection times across subjects as a function of Change Type in the Uncued and Cued conditions. Error bars indicate standard error for each Change Type in each condition.

referred to as *configural colour* changes. In contrast, colour changes that maintain the distinction between objects or regions (such as those used in this experiment) are referred to as *regular colour* changes (Fig. 3). In Experiment 2 we used this manipulation to further explore the roles of surface and configural properties in scene memory.

EXPERIMENT 2

Methods

Subjects. Subjects were members of the Brown University community who participated for course credit or pay. There were 24 subjects in the Uncued condition and 23 subjects in the Cued condition. No subject ran in more than one condition or either condition of Experiment 1.

Materials, Design, and Procedure. The materials used in Experiment 2 were similar to those used in Experiment 1. A total of 43 scenes were collected from the PhotoDisc CD Sampler (PhotoDisc Inc., Seattle, WA). Most of these scenes were the same as those used in Experiment 1. However, some new scenes were selected because we wished to create a sub-set of 17 scenes in which each scene could undergo a regular or a configural colour change.



Original



Regular



Configural

Changed

FIG. 3. An example of a regular colour change as compared to a configural colour change. Note in the configural case how the fruit changes from being two distinct regions into a single region (see circled part of each scene).

Scenes were chosen so that they contained two adjacent objects, medium to large size relative to other objects in the scene, one of which could realistically be either exactly the same colour or a different colour from the adjacent object thereby creating a unitary surface or collection of items. Regular colour changes involved an object or part of a scene changing to a colour that was different from its previous colour and from the surrounding objects. On the other hand, configural colour changes were those in which the critical object was changed to the same colour as an adjacent object, thereby creating a unitary surface spanning both items. The new colours were chosen to match the original colours as closely as possible in brightness. Both configural and regular colour changes were also chosen to be as realistic in the context of the scene as the original colours. These two measures, along with the fact that both types of colour changes covered *identical* regions in the scene, insured that the only major difference between scenes with configural and regular colour changes was that

the target region consisted of either two differently coloured patches or a single patch of one colour.

In Experiment 2, the sub-set of 17 scenes was used for colour changes of either type and a second set of 26 scenes was used for position and presence/absence. As in Experiment 1, each scene was only shown with one change type per subject. Within these sub-sets, which particular scenes were used for regular vs configural colour changes and for position vs presence/absence changes was counterbalanced across subjects. All other procedural aspects of Experiment 2 were as in Experiment 1.

Results and Discussion

Two-sample (with subjects as the random factor) and matched-pair (with scenes as the random factor) *t*-tests were then used to compare the means for each change type between the two conditions. In the Cued condition neither the position nor the presence/absence change detection times were facilitated relative to those in the Uncued condition; position and presence/absence, both $t < 1$. In contrast, both the regular and configural colour changes were detected faster in the Cued condition relative to the Uncued condition; configural $t(45) = 2.88$, $p < .01$, regular $t(45) = 3.58$, $p < .001$. However, there were no statistical differences in the detection times between the regular and configural colour changes in either the Cued or the Uncued conditions, both $t < 1$ (Fig. 4). A similar pattern was observed when the detection times were analysed using scenes as the random factor: configural, $t(16) = 3.23$, $p < .005$, regular $t(16) = 2.52$, $p < .05$, and position and presence/absence, both $t < 1$.

Surprisingly, the detection times and the extent of facilitation due to cueing did not differ in the regular and configural colour change conditions (although we did replicate the cueing advantage seen for colour as compared to position and presence/absence obtained in Experiment 1). Therefore using the flicker paradigm we were not able to obtain evidence that colour can function as a configural property. Alternatively, the critical difference between colour changes and position and presence/absence changes is not based on the configural/non-configural distinction.

GENERAL DISCUSSION

Despite our experience of veridicality, there is ample evidence that we do not reconstruct a complete description of the 3D scene (Simons & Levin, 1997). Indeed, recent work using a variety of "change detection" techniques indicates that many scene elements do not seem to be encoded in visual memory (McConkie & Currie, 1996; Rensink et al., 1997; Simons, 1996). Here we used one of those techniques, the "flicker paradigm," to assess the degree to

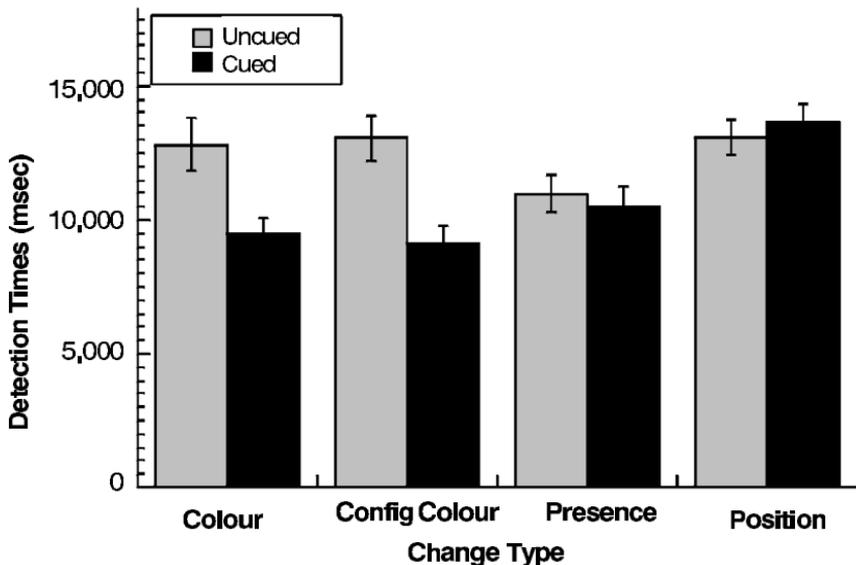


FIG. 4. Experiment 2. Mean change detection times across subjects as a function of Change Type in the Uncued and Cued conditions, including the configural colour change manipulation.

which different visual properties, *independent* of their conceptual significance, are represented. Our hypothesis was that cueing a subject with the property that was to change would facilitate detection to a greater extent if the property was, by default, only poorly encoded in visual memory. We compared changes across two configural properties that are likely to be more salient in memory, position and presence/absence, and across one non-configural property that is likely to be less salient in memory, colour. We found that colour changes were indeed detected faster when a valid cue was presented before each trial as compared to when no cue was provided. In contrast, no cueing facilitation was observed for position or presence/absence changes. In a second experiment we explored whether colour could serve as a configural property under certain conditions. Interestingly, we did not find any difference in cueing facilitation between configural and regular colour change conditions; both types of colour change were facilitated more than either position or presence/absence changes. Therefore, at least within the flicker paradigm, colour was treated similarly whether or not it produced configural changes in the scene.

One concern with this conclusion is that despite the fact that we attempted to keep the “size” of the changes consistent across different scenes and change types, physical aspects of each change type drove our effects rather than the type of change *per se*. In particular, we did not have a systematic way of measuring the signal strengths of the different changes. Because we used three

very different properties, which were not necessarily processed at equal rates by the visual system, we could not directly compare detection times for those properties. Thus, comparing cueing effects within a change type presumably eliminated this problem. However, it is still possible that the overall signal strength of the colour changes was higher than the overall signal strength of either position or presence/absence changes or both. Thus, the cueing effect for colour could have occurred simply because colour changes were more perceptually salient. In other words, even for properties requiring a similar amount of attentional and memorial resources, the difference between Cued and Uncued detection times for a more salient change could be larger than for a less salient change (independent of the type of change).

In order to examine this possibility we asked a new group of 18 subjects to rate the salience of each change within each scene that was presented in Experiment 1. These new subjects viewed the same displays—the flickering scenes—as were shown in Experiment 1. However, this time as soon as a scene appeared the experimenter pointed out the change that was occurring so that the subject did not have to search for it. This was done so that the subjects' ratings would not be biased by how difficult it would have been for them to detect the change. Each change was rated on a scale of 1 to 10, with 1 denoting the lowest salience and 10 denoting the highest salience. The rating results indicate that viewers did not perceive the colour changes to be more salient than the presence and position changes (Fig. 5). In fact both the colour and position changes were judged to be equally low in salience (mean of 3.13 for colour and mean of 3.12 for position) while the presence changes were rated somewhat higher (mean of 4.70). As illustrated in Fig. 5 there was no systematic relationship between the magnitude of the cueing effect and the rated salience of a given scene. This was true across all scenes $r = -.17$, and for each individual change type, colour: $r = -.23$; position: $r = -.14$; presence: $r = -.03$.

This analysis indicates that the cue effect observed for colour changes in the first two experiments was not due to colour changes being more prominent than presence or position changes. The low ratings suggest that colour changes were remarkably low in salience and no more salient than position changes. However, detecting colour changes was faster overall than detecting either presence/absence or position changes. Thus salience predicted neither the magnitude of the cueing effect nor the absolute detection times—a metacognitive error similar to that reported in Levin, Momen, Drivdahl, and Simons (this issue).

It is also worth noting that similar advantages have been observed in other types of visual search tasks. For example, Treisman (1988) reported that searching for targets defined by a single unique feature was fast and easy regardless of the number of distractors. Furthermore, searching for several different targets is easier if the specified features are drawn from a single perceptual dimension (e.g. blue, red, or yellow bar) rather than to multiple dimensions

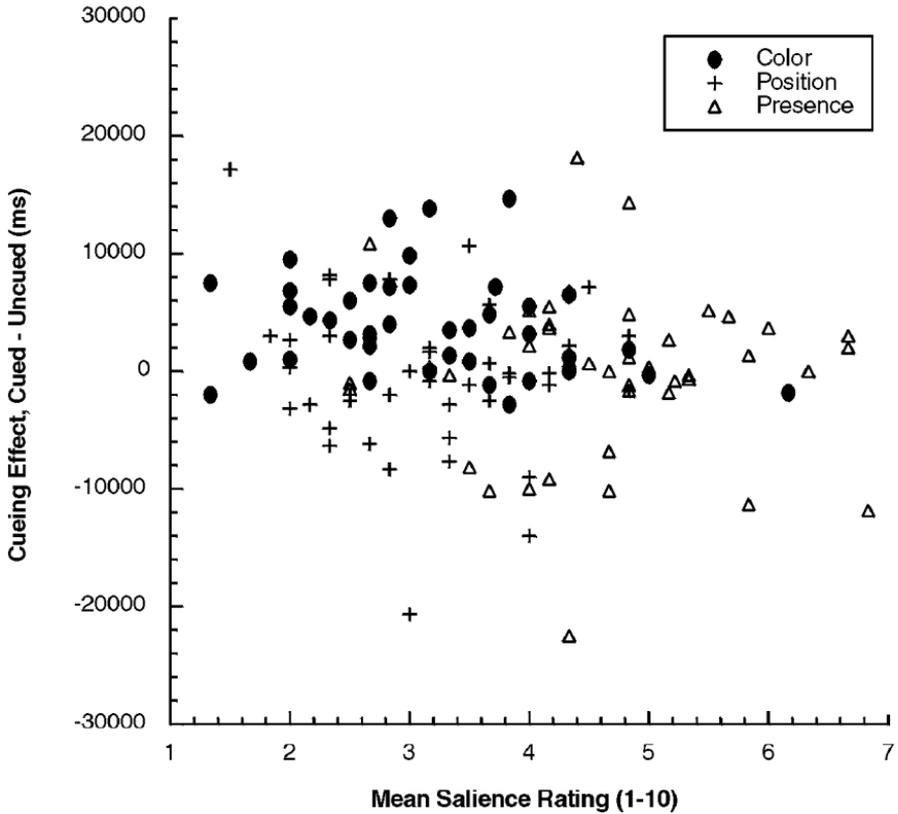


FIG. 5. Rated Salience vs Cueing effect (Cued–Uncued) of the change for individual scenes. Scenes are also distinguished by the Change Type (colour, position, and presence).

(e.g. blue or diagonal bar). Treisman also found that pre-cueing the position of an object facilitates the detection of conjunction targets but not the detection of single feature targets. Although such findings are consistent with the results we have presented, they do not address the issue of how such properties are encoded in visual memory. Moreover, the methodology used by Treisman does not distinguish between the potentially different roles played by different visual properties such as colour, shape, or orientation. Finally, in Treisman's study subjects searched for specific feature values and not for unspecified changes in specific feature maps.

There have also been previous findings of attention-related effects that distinguish colour from other visual properties. For example, Day (1978) and Miller (1978) both found that cueing specific colours decreased target search times, whereas cueing specific forms did not facilitate and sometimes even interfered with visual search. However, this effect was again observed for

specific colours, not for the dimension of colour. Our experiments build upon these findings but, unlike the past studies, investigated the role that colour and other properties play in perceiving natural scenes. Such stimuli are interesting because we were able to examine the processing of specific visual properties while attention was being guided within a natural scene and not a simple array of unrelated objects.

More specifically, our results suggest that when viewing natural scenes the active allocation of attention seems necessary for observers to effectively encode colour information. On the other hand, configural scene properties such as position and presence/absence appear to be somewhat better encoded without the need for the active deployment of attention. Consistent with this interpretation, it is widely held in the vision and attention literature that spatial position has a special status (for a review see van der Heijden, 1993). With specific reference to scene perception, it is thought that position is integral to the first stage of a two-stage process in which a scene is first automatically segmented into distinct regions (Schyns & Oliva, 1994). This initial processing establishes a "map of locations" to which attention can then be guided for the purpose of further analysis of detail features such as colours and complex shapes (e.g. Treisman & Gelade, 1980; Wolfe, Cave, & Franzel, 1989). Our results are compatible with this framework.

In our experiments the explicit detection of colour changes seemed to require attentional resources above and beyond those normally allocated to different visual properties of a scene—therefore, colour appears to be less critical in scene perception relative to configural properties. However, we cannot and should not rule out the possibility that in some instances colour can play a more primary role in scene processing. For example, it has been suggested that surface features such as colour may aid in the preattentive segmentation of a scene into distinct regions (Biederman & Ju, 1988; Wurm, Legge, Isenberg, & Luebker, 1993). Such a mechanism might provide a coarse spatial layout of colour, texture, and lightness patches that denote different regions that are candidates for further processing. Supporting this idea, Schyns and Oliva (1994) presented evidence that coarse information is indeed extracted before the viewer can consciously identify any semantic elements of the scene. This spatial layout representation can then prime the explicit identification of the scene as well as objects within the scene (Sanocki & Epstein, 1997; Schyns & Oliva, 1994).

To summarize, we obtained better cueing facilitation for detecting changes in colour as opposed to changes in either position or presence/absence. This was true whether or not the colour changes produced changes in the configuration of the scene. Such results suggest that independent of its conceptual valence, colour is not as salient in scene representations as configural properties such as position or presence/absence. Of course, it is possible that although our configural colour manipulation did produce a difference in the type of

layout representation that was extracted preattentively, the flicker paradigm was not sensitive to its effects. Perhaps colour-related changes in the configuration of a scene will influence performance in a task which taps into early scene processing.

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