Neurocase (1997) Vol 3, pp 237–247

The Role of Color in Object Recognition: Evidence from Visual Agnosia

Daniela Mapelli and **Marlene Behrmann**[1]

Department of Psychology, University of Padova, Italy and [1]Department of Psychology, Carnegie Mellon University, Pittsburgh, USA

Abstract

The extent to which the presence of color in a visual display (perceptual or surface color) assists object recognition has been much debated. Whereas edge-based theories argue that perceptual color is not helpful, surface-based theories claim that color is a valuable and salient clue. Consistent with the edge-based account, we showed that surface color plays a minimal role in aiding object recognition in a brain-damaged patient with an object recognition deficit (visual agnosia) but normal color processing. We found, however, that under certain conditions, such as when shape is ambiguous, stored knowledge of color can help disambiguate the object. Based on these results, we argue that the contribution of perceptual color is small but that long-term color knowledge plays an important top-down role in object recognition.

Introduction

The extent to which the presence of color in a display assists object recognition has been a matter of much debate. Whereas some theories argue that perceptual or surface color is not helpful, others claim that color is a valuable and salient clue and facilitates object recognition. The findings thus far are controversial and there is, as yet, no clear consensus on this issue. A related issue concerns the contribution of stored color knowledge to object recognition, and the question is whether long-term knowledge of an object's color assists recognition of the object in the absence of perceptual color (such as when the display is presented in black and white). We present data from a brain-damaged patient with a marked object recognition deficit (visual agnosia) who has well preserved color processing. We show that perceptual color assists his object identification minimally in a bottom-up fashion but that he is able to use his long-term semantic knowledge of color in a top-down fashion to disambiguate objects and that this is especially so when faced with structural uncertainty about the presented objects. We briefly discuss the pertinent findings from studies of perceptual color and stored color before describing the patient and our own experiments.

Perceptual color and object recognition

In vision research, two accounts of object recognition can be distinguished according to the emphasis each places on the role of surface information (such as color, brightness and texture) in defining the physical description of a stimulus. *Edge-based* theories claim that objects are initially recognized solely on the basis of their shape and that surface characteristics play a secondary role in primal access between a perceptual input and its underlying representation. For example, Biederman and his colleagues (Biederman, 1987; Biederman and Ju, 1988) maintain that edge-based components are critical for recognition and that three-dimensional volumetric primitives or geons, used in later stages of visual processing, are derived from two-dimensional edge-based representations of objects. Accounts like this emphasize the centrality of an edge-based or contour representation of an object but generally acknowledge that, under conditions of degradation or occlusion or where objects have identical volumetric descriptions, surface information may become important for recognition (Witkin and Tenenbaum, 1983; Grossberg and Mingolla, 1985; Riddoch and Humphreys, 1987; Ullman, 1984).

In contrast to these edge-based accounts, *surface-based* theories propose that surface information is critical early on in visual processing and plays an important role in establishing a primal and a 2½D sketch of an image (Marr, 1982). Thus, the recognition of visual entities may be based on multiple cues, in which both contour and surface information provide simultaneous, possibly interactive,

Correspondence to: Marlene Behrmann, Department of Psychology, Carnegie Mellon University, Pittsburgh, PA 15213-3890, USA. Fax: (412) 268-2798 e-mail to either: behboo@ux1 unipd.it or behrmann+@cmu.edu

routes to recognition (Bruner, 1957; Gibson, 1969; Farah, 1990; Farah *et al.*, 1994). In contrast to edge-based accounts, then, surface-based theories argue for a central role for surface information and predict that recognition will benefit when objects are depicted along with their surface details, relative to a display in which the surface features are absent.

One surface characteristic that has received considerable attention is that of color. Surface-based theories predict that chromatic pictures should be recognized faster than achromatic pictures, but edge-based theories predict no difference between them. Consistent with the edge-based theories, several studies have demonstrated no differences in performance with color and achromatic versions of the same stimuli: subjects are not faster when naming or verifying (true/false judgments) pictures of common objects when they are presented in color compared with black-and-white (B/W) pictures (Biederman and Ju, 1988); categorial judgments (such as size or living/non-living judgments) are not facilitated with color stimuli relative to their B/W counterparts (Davidoff and Ostergaard, 1988), and subjects are not slowed in recognizing inappropriately colored objects (e.g. a blue tomato) compared with the appropriately colored object (e.g. a red tomato) (Ostergaard and Davidoff, 1985). In fact, Davidoff and Ostergaard (1988) conclude that 'We can think of no other visual characteristic of an object with so little effect on object recognition' (p. 541).

In contrast to the findings of a null effect of color in recognition, data from other experiments have shown that color processing may indeed play some role. For example, when objects are presented clearly and unmasked, a color advantage has been observed (Ostergaard and Davidoff, 1985; Davidoff and Ostergaard, 1988; Brodie *et al.*, 1991; Wurm *et al.*, 1993). Furthermore, Price and Humphreys (1989) showed that both object naming and superordinate classification were facilitated by congruent surface color and inhibited for incongruent color. The influence of color was particularly noticeable for objects from structurally similar classes for which fine discriminations were necessary to differentiate important details.

One possible resolution to this inconsistent set of findings is that color information may not be useful for the recognition of all objects, but may play a valuable role under a restricted set of circumstances. For example, as shown by Price and Humphreys (1989), surface dimensions may become more informative when objects from structurally similar categories need to be disambiguated. A further possible condition under which color may be useful is when identifying objects from natural categories; these objects are more likely to be difficult to differentiate perceptually from each other and color may then be a useful source of information (Price and Humphreys, 1989; Humphrey *et al.*, 1994). But objects from natural categories might benefit from color not only because there is overlap in the structural aspects of the display but because they also have stronger associations with color than do objects from artifactual (manufactured) categories. Therefore, it is these stronger associations between shape and color that might also bring about a stronger influence of color on object identification for natural objects.

The extent to which an object is associated with a particular color is referred to as diagnosticity. For an object like a BANANA, color is highly diagnostic because bananas have a characteristic color whereas for objects like CHAIR or MITTEN, color is not predictive of the object's identity. One might expect then that color might be more helpful for high- than for low-diagnostic objects even when the objects are presented as B/W displays. The results on diagnosticity, however, like those on color in general, are not consistent. Whereas Biederman and his colleagues (Biederman, 1987; Biederman and Ju, 1988) demonstrated no difference in performance as a function of diagnosticity, Tanaka and Bunosky (unpublished results) found that diagnosticity facilitates performance across a wide range of tasks including object classification, naming and visual search. Tanaka and Bunosky suggest that whereas some objects may be represented and recognized exclusively on the basis of their shape (low color diagnostic objects), other objects may be recognized on the basis of their color and their shape (high color diagnostic objects).

However, diagnosticity or the extent of the association between an object and its color is not simply a perceptual effect. While the presence of color in a display may cue the viewer to a particular object in a bottom-up fashion, long-term knowledge might also be involved. Thus, when a subject sees a high diagnostic object repeatedly, the association of color and shape is strengthened and color likely becomes an integral attribute of the object's long-term representation (Tanaka and Bunosky, unpublished results). Diagnosticity, then, can be used in both a bottom-up and a top-down fashion. The presence of color in a display might cue and constrain a potential subgroup of candidate objects and thus activate the corresponding object more quickly for high- than for low-diagnostic objects. However, the association between an object and its color may also be more strongly activated in a top-down fashion for high- than low-diagnostic objects. This top-down effect operating alone may be seen when comparing high- and low-diagnostic objects when the display is monochromatic. Finally, interactions might be observed such that the presence of color in a display might be particularly helpful for objects for which stored color knowledge is strong. This would predict that performance will be best for high-diagnostic objects in color displays and poorest for low-diagnostic objects in monochrome displays, an issue we will return to in our experiments.

Stored color knowledge and object recognition

In this section we describe some existing data concerning stored color and its contribution to object recognition. A particularly clear series of studies demonstrating the contribution of stored color knowledge to object recognition have been reported recently by Joseph and Proffitt (1996). They demonstrated that the presence of color in a display may be helpful in object recognition but that stored knowledge of object color may play an even greater role than perceptual color. In the first experiment they showed that perceptual color does facilitate recognition: in a verification task, they presented subjects with a congruently (red apple) or incongruently (purple apple) colored line drawing which was followed by a label which either matched the picture (the written label 'apple') or did not (the label 'dog'). Subjects were significantly faster to verify the label when it was preceded by a congruently colored object than by an incongruently colored object. In the second experiment, they showed that stored color knowledge (semantic information of the prototypical color of objects) also significantly affected recognition; when subjects were shown a B/W picture of an apple, subjects responded faster when the subsequent label depicted an object that shared stored color with apple (e.g. cherry) than when it did not share stored color (e.g. blueberry), even though cherry and blueberry were judged to be equally visually similar to apple.

The crucial result, however, came in the final experiment in which they compared verification time for a pictured object, such as an apple, followed by a written label which could refer to (a) the identical object (label: apple), (b) an object with the same shape and color (cherry), (c) an object that shared shape but not color (blueberry) and (d) an object that shared neither shape nor color (hippo). They found that, first, shape information was critical and that the more discrepant the two items were in shape (e.g. apple, hippo), the easier it was to reject the pairing. They argued that if shape is not a sufficiently powerful cue (as in conditions b and c), stored knowledge of an object's color might play a crucial role and even override the contribution of surface color. Indeed, when the incongruently colored purple apple was followed by the label 'cherry', subjects took longer (123 ms) to reject and made more errors (6%) than when the label was 'blueberry'. This result is particularly counterintuitive; even though the surface color of the apple (purple) was shared with blueberry and one might predict that this similarity might make it harder to reject the label 'blueberry', there was greater interference from the fact that, in the world, apples and cherries share stored color (red). In another example, subjects confused a picture of an orange-colored asparagus more with the label 'celery' (shared stored color with asparagus) than with 'carrot' (shared perceptual color with this display of asparagus). These findings suggest that object decisions are more influenced by semantic color knowledge – that apple and cherry and asparagus and celery are known to share color – than by the visually presented color, especially when shape is ambiguous. The major result from this work is that the stored color associated with more conceptual stages of processing and likely mediated by the ventral temporal lobe anterior to the region involved in color perception (Martin *et al.*, 1995), plays a more powerful role than perceptual color (for related work, see Hanna and Remington, 1996).

Color and object recognition in agnosia

As is evident from the above discussion, there are potential contributions from both surface and stored color knowledge. At present, the exact extent of the contribution of surface color to object recognition still remains unclear; some claim that it is facilitating and some claim that it is not. Even of those who claim that it does facilitate, however, its contribution appears to be small relative to that of top-down knowledge of color. One source of evidence that might help clarify the contribution of surface and stored color comes from neuropsychological patients who have a selective deficit in form or shape recognition (visual object agnosia) despite adequate elementary visual functions, including visual acuity, visual fields, visual scanning and attention, as well as preserved general mental ability (Farah, 1990; Humphreys *et al.*, 1994). A number of such patients have preserved color processing (Adler, 1950; Benson and Greenberg, 1969; Efron, 1968; Farah, 1990; Grossman *et al.*, 1997) and, as such, allow us to examine the effects of color on their object identification ability. These patients are particularly interesting and may be dissociated from those patients who have impaired color but intact shape processing (see Tranel, 1997, for review).

Some neuropsychological evidence favoring the contribution of perceptual color comes from a study of one agnosic patient, DF, who had poor object recognition but preserved color processing. Interestingly, DF showed significantly better recognition of color than monochrome objects, both when these were presented as real objects as well as in 2D depictions (Humphrey *et al.*, 1994). Although Humphrey *et al.* showed the beneficial effect of color in object naming (particularly for natural objects) in DF as in their normal subjects, we do not know whether stored color knowledge might have been as useful, or even perhaps more useful, for her.

To extend this line of research, we first examine the role of surface color in an agnosic patient, JW, who, like patient DF, has well preserved color recognition but is markedly impaired in shape recognition and discrimination. We then examine the extent to which top-down knowledge of color could be used by JW. We found that surface color was only minimally helpful for JW but that top-down knowledge could assist in recognition, especially under conditions when shape was uninformative and where stored color knowledge was strong.

Subject

JW is a 38-year-old left-handed English-speaking white male with a Master's degree in computer programming. In

September 1992, he suffered a severe cardiac event while exercising on a Nordic Track. He collapsed in a state of ventricular fibrillation with pulmonary edema and remained unconscious for ~30 min. Following this incident, he was diagnosed with anoxic encephalopathy. Two CT scans of the head (multiple axial cuts obtained without contrast), one performed during the week of the incident (September 1992) and a second performed 1 month later (October 1992), showed no focal mass, no hemorrhage and no obvious infarct. An EEG performed at around the same time revealed the presence of intermittent generalized slowing and persistent slowing of the posterior background rhythm; the EEG also documented an intermittent spike and wave activity emanating from the right central parietal region. A later CT scan of the head, performed in October 1994, showed the ventricles to be symmetrical in size and position. Multiple hypodensities were noted in both occipital lobes, consistent with remote ischemic infarction. There was no sign of acute hemorrhage. The final diagnosis was of generalized atrophy and ischemic infarction in both occipital lobes, extending into the right parietal region. The EEG, performed during this same period (October 1994), showed diffuse slowing in the theta range with focal intermittent delta activity of a non-rhythmic nature emanating from the left fronto-temporal region. The diagnosis was an abnormal EEG with diffuse slowing, which is a non-specific indicator of generalized cerebral dysfunction, and with a superimposed intermittent delta slowing in the left cerebral hemisphere. The diffuse brain changes are consistent with multiple anoxic episodes.

JW recovered well and regained speech and motor skills but was left with a persistent and severe deficit in visual processing. Goldmann perimetry (central 76 point screening test and kinetic test) revealed a left upper quadrantanopsia, consistent with a lesion in the right hemisphere. A vision examination (April 1995) revealed acuity of OU 20/200. Pupils were responsive to light and eye movements full although somewhat hesitant in all quadrants. No apparent pathological changes were noted in the internal evaluation of the eye. JW has been unable to work since the incident. He has, however, re-learned to touch type on a computer and has acquired an optiscanner that converts text into speech. He currently works as a volunteer at a center for the blind. JW has been described in other publications and the reader is referred to those for more information on his perceptual abilities (Mapelli and Behrmann, unpublished results; Vecera and Behrmann, 1997) and his reaching performance and depth perception (Marotta *et al.*, 1997).

Neuropsychological examination

The testing reported here was conducted between July 1994 and February 1995. JW consented to participate in this study. JW's language comprehension and spontaneous speech expression were normal, as confirmed by the scores on the non-visual subtests of the Boston Diagnostic Aphasia Examination (Goodglass and Kaplan, 1972). He was well oriented in time and space and was very cooperative during the testing. He did not show any obvious short-term memory problem, and his span was 8 forward and 4 backward for digits and 5 forward for words. He has no problem recalling events that occurred either prior to or after the incident, although his recollection of the events immediately preceding and following the incident is impaired.

JW recognized only 21 of 39 three-dimensional common objects presented to him. While a few of his errors were a result of his mild anomia, for example, OCTOPUS → 'it's a sea creature', he generally failed to recognize the object and was unable even to guess at the object's identity. He could not describe (nor gesture) the functions of the objects he failed to recognize nor did he appear to possess semantic information for these objects, ruling out the diagnosis of optic aphasia. To confirm that the deficit was restricted to visual input and was not the result of a more general semantic deficit, we asked JW to provide definitions in response to the auditory label for the 18 objects that he failed to recognize when presented visually. He provided excellent definitions of all the objects. He also recognized correctly 38 of the same 39 objects when they were presented to him in the tactile modality. His good recognition from tactile or auditory input (even of the very objects that he failed when presented visually) suggests that his object recognition deficit is restricted to the visual modality.

JW's visual recognition was worse with B/W two-dimensional line drawings than with three-dimensional objects and he named correctly only two out of 34 randomly selected line drawings (Snodgrass and Vanderwart, 1980). Again, the verbal descriptions of the failed items, in response to their auditory label, were all appropriate and detailed. The superiority in recognizing 3D objects over 2D objects as shown by JW has been documented repeatedly both for brain-damaged and normal subjects (Campion, 1987; Humphrey *et al.*, 1994; Humphreys and Riddoch, 1987; Jankowiak *et al.*, 1992) but whether the relative difference is due to the absence of color in the drawings or to the absence of other surface information such as depth is not yet known.

Color processing

Because the goal of this study was to investigate the role that color plays in object recognition, we first demonstrated that JW's color perception was well preserved. We administered the Farnsworth-Munsell 100-hue test for color discrimination (1957) using the standardized procedure that requires ordering of colors on hue. In addition, 25 additional caps for the testing of the black-white (grayscale) continuum were administered. JW performed this task well and his error score was 82, reflecting performance within normal limits. An error score of 20 to 100 is achieved by 68% of the normal population in the first administration of the test. JW made only three errors on the grayscale caps, again showing competence in the discrimination of subtle changes in hue. These results suggest that, for the colors tested and for grayscale hues, JW's discrimination is well within normal limits. These data are consistent with our previous finding that JW, like normal subjects, showed preattentive color 'pop-out' on a visual search paradigm – his reaction time to detect the presence of a target defined by color (for example, a red horizontal bar amongst yellow horizontal distractors) was unaffected by the number of distractors present in the field (Mapelli and Behrmann, unpublished results). Although his base reaction time was somewhat slower than that of the matched normal control subjects, target detection occurred in parallel across the display and was independent of the size of the display. These findings confirm the integrity of JW's color processing and fit with the many previous reports in which patients with visual agnosia have preserved color vision.

Experiment 1: Naming color and B/W objects

As previously documented, JW performs poorly when asked to identify three-dimensional real objects, but the deficit is even more exaggerated when he is presented with two-dimensional B/W line drawings. What contributes to this difference is not known, given that many surface dimensions such as depth, color, luminance and texture may all differ in the two- and three-dimensional testing conditions. To examine the extent to which the presence of perceptual color assists in recognition, JW was required to name several sets of pictures presented in B/W on one occasion and in color on a second occasion.

Method

Three different sets of stimuli were used in this experiment:

1. Line drawings depicting the 39 three-dimensional common objects previously presented to JW (see Case report) were hand-drawn. Each object was drawn once in black and white and once in the correct color (e.g. the 'can of coke' was colored in red and white and the 'pear' in browns and greens), for a total of 78 line drawings. This set of line drawings not only provides a means of comparing the same color versus B/W pictures but also a means of comparing the 2D pictures with their corresponding real 3D objects.
2. The 60 line drawings taken from the Boston Naming Test (BNT; Goodglass *et al.*, 1985) (average size 9 × 9 cm) were presented either in their original B/W format or were colored in the appropriate colors using pencil crayons. This experiment was also repeated a year after the initial administration using the exact same stimuli and procedure.
3. Twenty-four pictures, all of which were shaded and contained fine detail of the internal structure of the object, were selected from the MacMillan Visual Dictionary (Corbeil and Archambault, 1992). The chromatic pictures were used from the dictionary and the corresponding B/W versions were constructed by photocopying the colored objects in high-resolution monochrome and removing the extraneous written text.

The procedure was the same for all the sets of pictures: pictures were presented individually for an unlimited period of time and JW was required to name them. For each set, the B/W and colored pictures were blocked and tested in separate sessions at least a month apart. Accuracy of recognition across the B/W and corresponding colored objects was compared. To ensure that JW's failure to identify the objects was attributable to a visual recognition deficit *per se* rather than to a problem in the semantic or conceptual knowledge of the item, at the end of each session, JW was asked to describe items that he failed to recognize visually when the verbal label was provided to him auditorily.

Results and discussion

JW recognized correctly only 78 out of the total 366 pictures (21%). Most of his errors were 'no response' although occasional visual confusions were noted: A PAIR OF SCISSORS → 'eyeglasses', a PRETZEL → 'a sponge' and a HELICOPTER → 'bike'. Consistent with previous findings, JW did better with the 3D real objects (21/39; see above) in set 1 than with the 2D depiction of the very same objects, whether shown in B/W (7/39) or in color (12/39). Of most relevance to the present study is the comparison between JW's performance on color and monochrome displays. These findings are shown in Table 1 along with the results of the statistical tests. As is evident from this table, none of the comparisons across the four sets of pictures revealed a statistical advantage for the color over the B/W displays when tested individually. An analysis of the findings collapsed across all four sets, however, shows a trend towards a benefit for color over monochrome displays, $\chi^2(1) = 3.06$, $P = 0.06$, although this does not reach significance. Across the interval of a year separating the two administrations of the BNT (set 2), JW showed a significant improvement in performance, $\chi^2(1) = 23.1$, $P < 0.0001$, but, importantly, there was no difference

Table 1. JW's accuracy in recognition of monochrome and colored pictures

Test set	Monochrome	Color	Chi-square
Set 1	7/39	12/39	1.1
Set 2 (1st presentation)	3/60	9/60	2.3
Set 2 (2nd presentation)	17/60	22/60	0.6
Set 3	4/24	4/24	0
Total	31/183 (17%)	47/183 (26%)	

between monochrome and color in either of the two sessions [session 1: $\chi^2(1) = 2.3$, $P > 0.05$; session 2, $\chi^2(1) = 0.6$, $P > 0.05$]. These findings suggest that the perceptual color in the display plays a minimal role in object recognition for JW.

Interestingly, when attempting to identify the colored pictures, JW often focused on the colors first. Although the colors were invariably named correctly, he still failed to recognize most of the objects and this 'color first' strategy which JW adopted when confronted with a color picture was obviously not of much value in object identification. This is consistent with the view that almost no objects are defined uniquely by color and that knowing the color of an object ahead of time does not necessarily restrict the number of possible interpretations of the display. Wurm *et al.* (1993), for example, showed that explicit knowledge about color does not help in knowing what an object is; subjects were poor at guessing what a particular target object was when told its color (for example, green) even when they were also told what category the target belonged to (for example, food).

Experiment 2: Recognition of high- and low-diagnostic objects

The results thus far suggest that surface color only minimally aids JW's object recognition over and above monochrome displays. One outstanding possibility is that color is not *generally* useful in object recognition, but rather that its impact depends on the diagnosticity or degree to which color information is useful in identifying and recognizing objects. Although virtually no object can be identified by color alone, the colors of some objects (high diagnostic) are more symptomatic of an object than others (low diagnostic) and may therefore restrict the set of possible alternatives. It might be under these more limited conditions that the benefit from color is manifest.

To test whether JW's recognition performance improves for color over B/W line drawings when diagnosticity is taken into account, we presented to JW the high- and low-color diagnostic pictures used by Tanaka and Bunosky (unpublished results). If surface color plays some role in JW's object recognition (although the previous experiment suggests that it is limited), then we might expect to see that performance will be better with colored pictures than with their achromatic counterparts. If stored color plays a role then we might see better performance for high- than low-diagnostic objects even on the B/W displays. Finally, we might also expect to see better performance with high- than low-diagnostic objects for color displays both because of the bottom-up cues and because of the contribution of stored top-down knowledge.

Method

A set of 24 pictures depicting 12 high- and 12 low-diagnostic objects was selected from the MacMillan Visual Dictionary (Corbeil and Archambault, 1992). Each picture was presented in two different versions: a color version and an achromatic version, for a total of 48 pictures. The color version consisted of pictures of the objects in the colors in which they naturally or typically appear. The pictures were digitized using a MicroTek scanner and prepared for presentation using Adobe Photoshop graphics software. None of these pictures was the same as any used in previous experiments with JW. See Appendix A for the list of objects and Tanaka and Bunosky (unpublished results) for more details.

In one session, JW was presented with the achromatic version of the pictures, and, in the second session, he was presented with the colored version. The objects were presented individually on a Macintosh Powerbook 540c computer screen for an unlimited duration and JW named each one. In each session, high- and low-color diagnostic pictures were shown in randomized order and accuracy was recorded.

Results and discussion

JW recognized only 3/24 B/W and 5/24 colored pictures. These findings are consistent with the previous experiment in which there is a slight but non-significant improvement in JW's recognition of color over B/W drawings, $\chi^2(1) = 0.15$, $P > 0.1$. Of the eight correctly recognized objects, JW recognized four high- and four low-diagnostic pictures, respectively, with no significant bias favoring high-diagnostic objects, $\chi^2(1) = 0.15$, $P > 0.1$. There was also no interaction with the color of the display (color versus B/W) and no bias favoring high-diagnostic color objects. These results suggest that the contribution of surface color to identification is small, and that diagnosticity (whether through predictive bottom-up cues or through long-term association) does not significantly influence JW's object recognition.

Experiment 3: The role of color in object verification

The findings from Experiments 1 and 2 reveal little (if any) assistance from the presence of color in a display as shown in equivalent recognition of objects in color and B/W displays. Also, to the extent that color and object shape are bound in long-term knowledge, we see no obvious influence of diagnosticity on object identification as reflected in equivalent performance for high- and low-diagnostic objects (both in color and B/W displays). There is one final condition, however, in which we might still see color having an effect on JW's object recognition – when objects need to be finely differentiated from each other. As mentioned previously, there is general acceptance (even from edge-based theorists) that color may play a role when structurally similar objects need to be disambiguated or under conditions of degradation. In these cases, shape alone is not a sufficiently powerful cue and additional information is recruited to assist in recognition. Based on this reasoning, one might have expected color to be particularly helpful to JW as items are structurally ambiguous and degraded for him almost all the time. Apparently this is not the case. One possible explanation is that his object recognition might be too poor to generate a sufficiently useful shape description in the first place, in which case, using other sources of information, like color, might not be terribly helpful (a type of floor effect). When there is some shape information, however, albeit coarse, then color might come into play, as has been demonstrated before (Price and Humphreys, 1989).

The paradigm we used was similar to that of Joseph and Proffitt (1996) in that a picture was presented followed by a verbal label and the task was to determine whether they matched or not. As in Joseph and Proffitt, one condition contained a perfect match between the picture and the label (*identity* condition: e.g. lettuce, lettuce). In a second condition, the label depicted an object that was neither similar in color nor in shape to the picture (the *dissimilar* condition: e.g. lettuce, squirrel) and finally, in the third, *similar* condition, the label referred to an object that was structurally similar to the target but typically differed in color from the target (e.g. lettuce, cauliflower). The first and third conditions were the important ones and contained objects and labels for objects that were structurally similar. Moreover, for each condition, half of the objects were high and half low in diagnosticity. The question was whether, in a verification paradigm when structurally similar objects need to be differentiated, JW could resolve the ambiguity. Under these conditions, the two alternatives (label refers to same object or structurally similar object) were known to him and we were interested in whether the presence of color in the display and the manipulation of diagnosticity would be used to settle in favor of the correct verification response. In this study, then, we examine how well JW verifies object–label pairs when color is present in the display (perceptual color: B/W versus monochrome), when color is associated with an item (high/low diagnosticity), and when items are structurally confusable or not (same, similiar and dissimilar conditions).

Method

The 24 pictures, 12 high- and 12 low-diagnostic, used in the previous experiment, were also used in this experiment. Again, each picture was presented in two different versions, one color and one achromatic, for a total of 48 pictures. For each picture, there was a triad of labels: the correct label (identity), the name of a similar object (similar) and the name of a dissimilar object (dissimilar), making for a total of 144 picture–label trials. For example, for the object 'brick', the identity label was 'brick', the similar object label was 'sponge' and the dissimilar object label was 'mouse' (see Appendix A for a complete list).

The experiment was run twice with an interval of a year between the two testing periods. For each administration, two sessions were required, one each for the presentation of the B/W and colored displays. During each session the same picture was presented three times, in pseudo-random order such that at least three pictures intervened between successive presentations of the same picture. Each item was coupled once with the identity label, once with the similar label and once with the dissimilar label. No label was used to refer to more than one object. On each trial, the picture appeared on the computer screen and the experimenter asked whether it matched the label; for example, when the picture of the brick appeared, the question posed was 'is this a brick?'. JW simply responded 'yes' or 'no' and accuracy was recorded. Because JW is poor at reading, the labels were presented to him auditorily rather than visually, as was the case in the Joseph and Proffitt study. The pictures were presented individually on a Macintosh computer screen for an unlimited duration until a response was made.

Results and discussion

As reviewed previously, in the Joseph and Proffitt study, subjects were able to reject pairing from dissimilar objects very easily and the main effects of color only came in when the pictured object and the object referred to by the label were structurally similar. The first question we asked in this experiment, then, was whether JW had sufficiently preserved (even if rather coarse) recognition to accurately reject the labels from the *dissimilar* condition and whether color (perceptual or stored) played any role in this process. More relevant, though, was whether, in the condition where the label referred to a structurally similar object, he might be able to use surface color to verify the match between the label and picture and, moreover, whether this was more likely to occur in the high- than in the low-diagnostic cases.

JW performed equally well on the two separate administrations of the experiment with correct identification on 120/144 and 119/144 trials on the first and second sessions, respectively, $\chi^2(1) = 0.15$, $P > 0.1$. For subsequent analyses, therefore, the data are collapsed across the two periods, for a total of 288 trials. The error rates as a function of surface color and diagnosticity for the three object–label pairings are presented in Fig. 1.

To determine whether presentation (B/W versus color), diagnosticity (high versus low) and/or picture–label pairing (identity, similar, dissimilar) influenced JW's performance, a multivariate logistic regression was used. As in the standard chi-square procedure, comparisons are made between observed and expected cell frequencies. This procedure, however, also allows various candidate models to be fit to the data and provides measures of goodness (or poorness, as reflected in a likelihood-ratio chi square) of fit. Different models, in hierarchical order, are fit to the data and interaction terms are systematically dropped from the fully saturated model until the most parsimonious model (i.e. has a non-significant P value) with the least number of parameters is obtained (see Kleinbaum, 1994, for theoretical discussion, and Buxbaum *et al.*, 1996, for an example of this method).

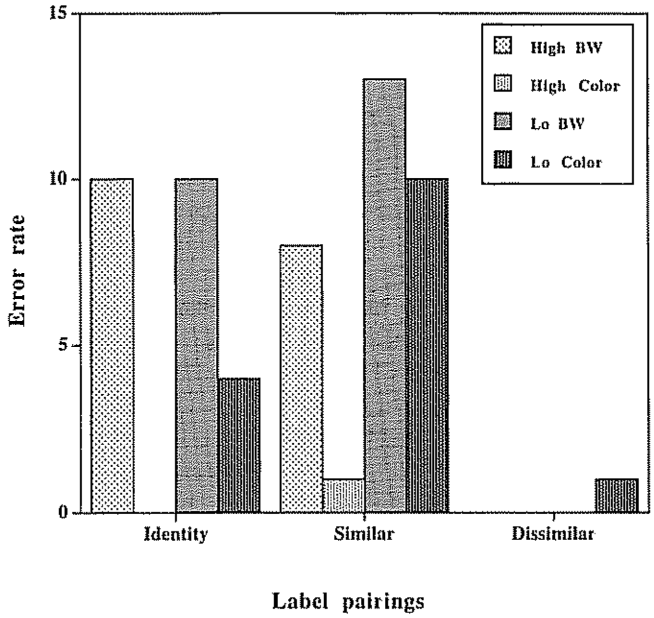

Fig. 1. Error rate for JW as a function of perceptual color and diagnosticity for the three object–label pairings (n = 24 per cell)

This procedure, applied to the present data, yielded a model which included all three experimental factors, presentation, diagnosticity and picture–label pairing interacting with the dependent measure of accuracy (G^2 = 0.76, df = 1, P = 0.38). Importantly, color, diagnosticity and label type jointly influenced performance (G^2 = 0.04, df = 2, P = 0.97), suggesting that this model adequately accounts for the data. When this three-way interaction is broken down, we see that performance in the dissimilar (95%) condition was better than in either the identity or similar condition, while these latter conditions did not differ from each other (identity 75%, similar 67%). The most important finding, however, was that the high-diagnostic colored objects were identified best in the identity and similarity conditions and that the B/W low-diagnostic objects were identified most poorly. This interaction between perceptual color and diagnosticity for the structurally overlapping picture–label conditions (including the identity and similar conditions) suggests that both color in the display and stored color knowledge play a role in JW's performance. There are also significant joint effects, reflected in poor fits of the two-way models, of perceptual color and diagnosticity, (G^2 = 0.71, df = 1, P = 0.4), color and object–label pairing, (G^2 = 1.95, df = 2, P = 0.38), and of diagnosticity and object–label pairing, (G^2 = 1.6, df = 2, P = 0.4).

These findings suggest, first, that in a verification task, JW was able to reject the dissimilar object–label pairs well and that color was unnecessary in this process given that he rejected pairs equally well for color and B/W displays when the objects denoted by the labels were structurally different from the target (e.g. brick, mouse). Secondly, his performance in the identity and similar conditions were not different in overall accuracy and he made more errors in these conditions than in the dissimilar condition, reflecting his poor object recognition. Most important, however, was that, in both conditions in which he had to make fine differentiations to determine whether the label referred to the structurally similar depicted object or not (e.g. lettuce–lettuce or lettuce–cauliflower), both perceptual color and diagnosticity in the display serve as a useful heuristic. This gives rise to best performance in the high-diagnostic color condition and poorest performance in the low-diagnostic B/W condition.

The benefit of color over achromatic displays under conditions of structural similarity is consistent with the findings of some verification studies (Joseph and Proffitt, 1996) and suggests that perceptual color does play some role in object identification. The benefit, however, is more obvious for high-diagnostic objects for which both stored and perceptual color is semantically salient and predictive, and the effect of color is particularly useful under circumstances in which the label refers to objects that are similar in shape to the target object. These findings suggest that perceptual color may serve as an additional cue interactively with long-term knowledge of color.

One important question is why we only see the emergence of positive findings of perceptual color and diagnosticity in Experiment 3 but not in Experiment 2. As alluded to previously, in Experiment 2, JW is performing a naming task and because of his profound impairment in object recognition, he is unable to derive sufficient shape information to produce a candidate as a response. In Experiment 3, even though the stimuli are identical to those used in Experiment 2, the task is a verification task and JW is provided auditorily with the label of an object and he decides whether the label refers to the presented object. JW has well preserved mental imagery for shape and color (Mapelli and Behrmann, unpublished results) and this long-term knowledge of shape may assist him in deriving sufficient shape information. This coarse information suffices to reject markedly discrepant pairs as in the dissimilar condition but is insufficient, on its own, for the structurally similar pairings. In these latter conditions (similar and identity), both perceptual color and stored color can then come into play. When both these factors are at work, performance is best; when neither is available, performance is poor.

General discussion

The question addressed in this study concerns the contribution of color information during object recognition and more specifically, whether color assists in object recognition. The benefit from color may arise in two potentially different ways: one is bottom-up when color is present in a display and the second is top-down from long-term stored color knowledge even in the absence of perceptual color. The findings on perceptual color have remained somewhat inconclusive despite the wealth of studies on normal subjects There does, however, seem to be an emerging consensus that stored color knowledge may play an important role in object identification and, in some cases, may be sufficiently powerful to override the contribution of surface color (Joseph and Proffitt, 1996) Additionally, it appears that the contribution of both perceptual and stored color may be enhanced when shape is not a sufficiently powerful cue on its own (Biederman and Ju, 1988; Price and Humphreys, 1989).

The focus of the present paper is to investigate the contribution of perceptual and stored color to the object recognition performance of a patient, JW, who has a profound object recognition impairment but preserved color processing following acquired brain damage. We reasoned that if perceptual color plays an important part in object recognition, JW might be expected to recognize and hence identify more objects when displayed in color than when displayed in B/W. Furthermore, to test for the contribution of stored color knowledge, we presented objects that were strongly predicted by color or not (high/low diagnostic). In a naming task, JW showed a minimal advantage with color displays over B/W (Experiments 1 and 2) and was not better at identifying high- over low-diagnostic objects (Experiment 2). We did, however, observe the joint effects of perceptual and stored color in Experiment 3 and this joint effect was particularly evident when objects were potentially confusable. In a verification task in which JW was supplied with a label and was required to decide whether this referred to the previously presented object or not, JW performed better with color than B/W displays, especially for the high-diagnostic objects and especially in conditions in which the label referred to a structurally similar (or identical) object. He also performed most poorly when neither perceptual color nor stored color was available to him (B/W low-diagnostic objects).

The joint effects of perceptual and stored color, however, only arose when JW had sufficient information about the objects' shape so that he was not totally debilitated. In a naming task in which an object was presented for identification, neither perceptual nor stored color was useful to him. It was only in a verification task in which he had sufficient shape information by virtue of having been provided with a label (although this shape information was still very degraded) that he was able to make use of color. When color became a viable heuristic, both perceptual and stored color knowledge had positive influences on his performance.

Taken together, these results suggest then that even though surface color is a seemingly salient perceptual dimension of the visual world and even though JW often uses this to bootstrap his impoverished recognition and makes 'color first' guesses, object recognition is not obviously helped by the presence of color in a display. The absence of a color advantage in all but the verification experiment is consistent with those studies that have argued that contour and edge-based information is central in object recognition and that color plays only a secondary role. The results also suggest that diagnosticity alone is not particularly helpful for JW (Biederman and Ju, 1988) We have argued, therefore, that surface color on its own is not a particularly useful cue in object recognition and, as such, the data are more consistent with edge-based theories of recognition where the primary information about the object's identity is conveyed through its boundary and configural information. Color diagnosticity is also not terribly helpful on its own but can be engaged when there is sufficient data-driven activation from a display.

The findings from the verification experiment are consistent with the claim of some computational vision systems that top-down color knowledge can be used as an indexing or matching device. In one such system when an item is presented, it is matched (via a histogram of the color) on the basis of color and shape to alternative stored possibilities in a large database of potential models. In this system, then, stored knowledge as well as perceptual knowledge contributes to object identification. Based on the success of a color algorithm like this for identifying what the target object is, Swain and Ballard (1991) argue that even if color is not useful in recognition in general, it can serve a useful top-down heuristic for robots.

There is one final consideration, and that concerns the difference between the two agnosic patients, DF (Humphrey *et al.*, 1994) and JW. For DF, the presence of color (and other surface properties) aided recognition by 19% relative to a monochrome display. This difference was even larger when only natural objects were counted. This benefit from surface color was not observed for JW. We have claimed that color only becomes a useful heuristic when there is sufficient shape information (thereby accounting for the difference between JW's naming and verification performance). One possibility then is that the critical difference arises in the amount of bottom-up or data-driven information available to DF compared with JW. JW has rather more widespread cortical damage than does DF (see Marotta *et al.*, 1997, for details) and perhaps is less able to derive a sufficient bottom-up description of the contours in the display. DF, on the other hand, may have sufficient bottom-up activation of shape information that her stored color knowledge may be engaged along with perceptual color and assist in object recognition. Whether or not the severity of the agnosia will determine the extent to which color can be truly useful remains to be confirmed. In any event, the study of agnosic patients who have preserved color processing can shed light on how surface properties influence object recognition.

Acknowledgements

We thank Dr G. Ratcliff and Ms T. Bunyarapatan of Harmarville Rehabilitation Center (HRC) for referring JW to us and for sharing their knowledge and expertise with us.

We acknowledge and appreciate the cooperation and goodwill of JW and his family. We thank Jim Tanaka for sharing his stimuli with us, James Nelson for help in data collection, David Plaut and Jane Joseph for their comments, Dr S. Small for discussing the neurological findings with us and Dr P. Freeman for sharing his ophthalmological findings with us. This work was done while the first author was visiting Carnegie Mellon University.

References

Adler A. Course and outcome of visual agnosia. Journal of Nervous and Mental Disease 1950; 111: 41–51.

Benson DF, Greenberg JP. Visual form agnosia: a specific deficit in visual discrimination. Archives of Neurology 1969; 20: 82–9

Biederman I. Recognition by components: a theory of human image understanding. Psychological Review 1987; 94: 115–47.

Biederman I, Ju G. Surface versus edge-based determinants of visual recognition. Cognitive Psychology 1988; 20: 38–64.

Brodie EE, Wallace AM, Sharrat B. Effect of surface characteristics and style of production on naming and verification of pictorial stimuli. American Journal of Psychology 1991; 104: 517–45.

Bruner JS. Going beyond the information given. In: Contemporary approaches to cognition. Cambridge, MA: Harvard University Press, 1957

Buxbaum LJ, Coslett HB, Montgomery MW, Farah MJ. Mental rotation may underlie apparent object-based neglect. Neuropsychologia 1996; 34: 1113–26

Campion J. Apperceptive agnosia: the specification and description of constructs. In: Humphreys GW, Riddoch MJ, editors. Visual object processing: a cognitive neuropsychological approach. London: Lawrence Erlbaum, 1987.

Corbeil JC, Archambault A. The MacMillan visual dictionary. New York: MacMillan, 1992

Davidoff JB, Ostergaard AL. The role of color in categorial judgments. The Quarterly Journal of Experimental Psychology 1988; 40A(3): 533–44.

Efron R. What is perception? In: Cohen RS, Wartofsky M, editors. Boston studies in the philosophy of science, Vol 4. Dordrecht: D. Reidel, 137–73

Farah MJ. Visual agnosia. Cambridge, MA: MIT Press, 1990

Farah MJ, Rochlin R, Klein KL. Orientation invariance and geometric primitives in shape recognition. Cognitive Science 1994; 18: 325–44

Gibson EJ. Principles of perceptual learning and development. New York: Appleton-Century-Crofts, 1969

Goodglass H, Kaplan E. The assessment of aphasia and related disorders. Philadelphia: Lea and Febiger, 1972.

Goodglass H, Kaplan E, Weintraub S. The Boston Naming Test. Philadelphia: Lea and Febiger, 1985.

Grossberg S, Mingolla E. Neural dynamics of perceptual grouping: texture, boundaries and emergent segmentations. Perception and Psychophysics 1985; 38: 141–71

Grossman M, Galetta S, D'Esposito M. Object recognition difficulty in visual apperceptive agnosia. Brain and Cognition 1997; 33: 306–42.

Hanna A. Remington R. The representation of color and form in long-term memory. Memory and Cognition 1996; 24: 322–30

Humphrey GK, Goodale M, Jakobson L, Servos P. The role of surface information in object recognition: studies of a visual form agnosic and normal subjects. Perception 1994; 23: 1457–81.

Humphreys GW, Riddoch MJ. To see but not to see: a case study of visual agnosia. London: Erlbaum, 1987.

Humphreys GW, Riddoch MJ, Donnelley N, Freeman T, Boucart M, Muller HM. Intermediate visual processing and visual agnosia. In: Farah MJ, Ratcliff G, editors. The neuropsychology of high-level vision. Hillsdale, NJ: Lawrence Erlbaum Associates, 1994

Jankowiak J, Kinsbourne M, Shalev RS, Bachman DL. Preserved visual imagery and categorization in a case of associative visual agnosia. Journal of Cognitive Neuroscience 1992; 4: 119–31

Joseph JE, Proffitt D. Semantic versus perceptual influences of color in object recognition. Journal of Experimental Psychology: Learning, Memory and Cognition 1996; 22(2): 407–29.

Kleinbaum DG. Logistic regression: a self-learning text. Springer: New York, 1994.

Marotta J, Goodale M, Behrmann M. Experimental Brain Research 1997; in press

Marr D. Vision. Freeman: San Francisco, 1982

Martin A, Haxby JV, Lalonde FM, Wiggs CL, Ungerleider L. Discrete cortical regions associated with knowledge of color and knowledge of action. Science 1995; 270: 102–5.

Ostergaard AL, Davidoff JB. Some effects of color on naming and recognition of objects. Journal of Experimental Psychology 1985; 11(3): 579–87.

Price CJ, Humphreys GW. The effects on surface detail on object categorization and naming. The Quarterly Journal of Experimental Psychology 1989; 41A(4): 797–828

Riddoch MJ, Humphreys GW. Picture naming. In: Humphreys GW, Riddoch MJ, editors. Visual object processing: a cognitive neuropsychological approach. London: Lawrence Erlbaum Associates, 1987.

Snodgrass JG, Vanderwart MA. A standardized test of 260 pictures: norms for name agreement, image agreement, familiarity and visual complexity. Journal of Experimental Psychology: Human Learning and Memory 1980; 6: 174–215.

Swain MJ, Ballard D. Color indexing. International Journal of Computational Vision 1991; 7: 11–32

Tranel D. Disorders of color processing. In: Feinberg TE, Farah MJ, editors. Behavioral neurology and neuropsychology. New York: McGraw Hill, 1997

Ullman S. Visual routines. Cognition 1984; 18: 97–159

Vecera S, Behrmann M. Spatial attention does not require preattentive grouping. Neuropsychology 1997; 11: 30–43

Witkin AP, Tenenbaum JM. On the role of structure of vision. In: Beck J, Hope B, Rosenfeld A, editors. Human and machine vision. New York: Academic Press, 1983

Wurm LH, Legge GE, Isenberg LM, Luebker A. Color improves object recognition in normal and low vision. Journal of Experimental Psychology: Human Perception and Performance 1993; 19: 899–911.

Received on 27 June, 1996; resubmitted on 13 March, 1997; accepted on 23 March, 1997

Appendix A: Listing of high- and low-color diagnostic objects as well as the object labels (similar and dissimilar) as used in the verification task

High diagnostic

Consistent	Similar	Dissimilar
Banana	Stapler	Mug
Brick	Sponge	Mouse
Broccoli	Bouquet	Bottle
Carrot	Pencil	Ring
Corn	Vase	Hand
Fire engine	Taxi	Glove
Lemon	Ball	Pen
Lettuce	Cauliflower	Squirrel
Lime	Bowl	Floppy disk
Radish	Cherries	Telephone
Stop Sign	Bage	Egg
Taxi	Sportscar	Computer

Low diagnostic

Consistent	Similar	Dissimilar
Bird	Hen	Radio
Chair	Sofa	Book
Dog	Cat	Table
Fish	Airplane	Television
Fork	Spoon	Lion
Hammer	Toothbrush	Door
Lamp	Mushroom	Key
Nail	Pen	Apple
Saw	Scissors	Flower
Screwdriver	Knife	Orange
Sportscar	Taxi	Bicycle
Round table	Umbrella	Strawberry

The role of color in object recognition: Evidence from visual agnosia

D. Mapelli and M. Behrmann

Abstract
The extent to which the presence of color in a visual display assists object recognition has been much debated Whereas edge-based theories argue that perceptual color is not helpful, surface-based theories claim that color is a valuable and salient clue Consistent with the edge-based account. we showed that surface color plays a minimal role in aiding object recognition in a brain-damaged patient with an object recognition deficit (visual agnosia) and normal color processing We found, however, that when the identity of a shape is difficult to determine, stored knowledge of color can help disambiguate the object Based on these results, we argue that the contribution of perceptual color is small but that long-term color knowledge plays an important role in top-down processing

Journal
Neurocase 1997; 3: 237–47

Neurocase reference number:
O80

Primary diagnosis of interest
Apperceptive agnosia

Author's designation of case
JW

Key theoretical issue
- The contribution of color in a display only minimally helps object identification but stored knowledge can disambiguate objects in a top-down fashion

Key words: agnosia; color; object recognition; surface cues

Scan, EEG and related measures
CT, EEG

Standardized assessment
Goldmann perimetry, Boston Diagnostic Aphasia Examination, Boston Naming Test, Farnsworth–Munsell 100-hue test for color discrimination

Other assessment
Nil

Lesion location
- Multiple hypodensities bilaterally in occipital lobes and extending into right parietal lobe.
- Generalized atrophy

Lesion type
Infarction

Language
English