Sensory and cognitive contributions of color to the recognition of natural scenes

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Although color plays a prominent part in our subjective experience of the visual world, the evolutionary advantage of color vision is still unclear [1–2], with most current answers pointing towards specialized uses, for example to detect ripe fruit amongst foliage [3–6]. We investigated whether color has a more general role in visual recognition by looking at the contribution of color to the encoding and retrieval processes involved in pattern recognition [7–9]. Recognition accuracy was higher for color images of natural scenes than for luminance-matched black and white images, and color information contributed to both components of the recognition process. Initially, color leads to an image-coding advantage at the very early stages of sensory processing, most probably by easing the image-segmentation task. Later, color leads to an advantage in retrieval, presumably as the result of an enhanced image representation in memory due to the additional attribute. Our results ascribe color vision a general role in the processing of visual form, starting at the very earliest stages of analysis: color helps us to recognize things faster and to remember them better.

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Results and discussion

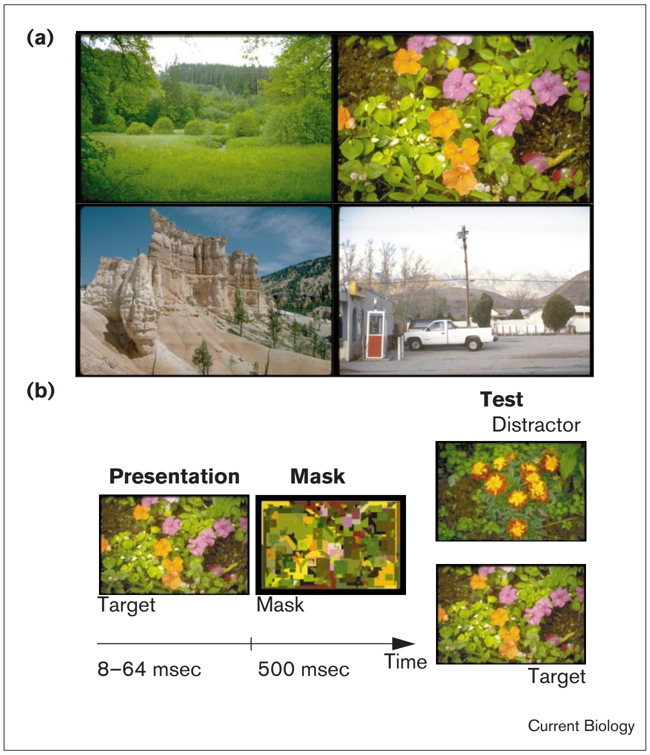
Recognition of natural scenes

A delayed match-to-sample task was used to test the role of color vision in the recognition of briefly presented images of natural scenes (Figure 1). Half of the images were presented in color, the other half in black and white. In order to differentiate between different contributions of color to recognition, half of those images presented in color were tested in black and white (the CB condition), the other half in color (CC). Half of the images presented in black and white were tested in color (BC), the other half in black and white (BB). Consequently, if the target is presented in color, but then tested in black and white, the color information *per se* cannot be used in the decision. It can only be used during the early sensory processes that lead to the encoding of the image [9], such as edge detection, texture segmentation or figure–ground segregation [8]. Therefore, any difference between the BB and CB conditions will reflect a sensory, or *coding*, advantage of color (Figure 2a). If color contributes at the cognitive level alone, then we would expect no difference between the BB and CB conditions. In contrast, the sensory contributions are identical for the CC and CB conditions, as in both cases the target image is presented in color. Any difference between the CC and CB conditions is therefore caused during the process of comparing the target image with its representation in memory. An advantage would probably be caused by having color contribute to that *representation* as an additional attribute. We will refer to this as cognitive facilitation.

Figure 2b shows the results. Not surprisingly, the proportion of correctly recognized images increased rapidly with presentation duration. But, even at the very short presentation duration of 16 milliseconds, subjects were performing clearly above chance (68.7% correct, ± 1.55% SE), indicating that these highly complex stimuli can be processed very quickly [10]. We performed a within-subjects analysis of variance on the frequencies of correctly recognized images by each subject, summed over the four image categories. Significant effects of presentation duration ($F(3,57) = 78.85$, $p < 0.001$) and color ($F(3,57) = 9.31$, $p < 0.001$) were revealed. The recognition of images presented and tested in color (CC) was significantly better than that of black and white images (BB) at all presentation durations, including the shortest one. Interestingly, at that presentation duration (16 msec) there was no difference between the CB and CC conditions ($t(19) = 0.93$, $p > 0.05$), with both being superior to the BB condition ($t(19) = 2.14$, $p < 0.05$). At the longest presentation duration, 64 milliseconds, the opposite occurs, however. Images presented in color are recognized better ($t(19) = 6.47$, $p < 0.05$), but only when they are also tested in color (CC). Here, there is no difference between the CB and the BB conditions ($t(19) = 0.87$, $p > 0.05$). For intermediate presentation durations we observed a gradual transition between the two.

Our results suggest that color contributes to recognition in two distinct ways. At the earliest stages of visual processing, color information leads to a coding advantage, shown by the fact that for very brief presentations (16 msec) recognition was better for images presented in color, even when they were tested in black and white. This excludes

Figure 1



Experimental procedure. **(a)** Images from four different categories, representative of our visual environment, were tested: green landscapes, flowers, rock formations and snapshots including man-made objects. **(b)** On each trial a target image was briefly presented (16–64 msec) and immediately followed by a noise mask with a duration of 500 msec. Then the target image was presented together with a distractor from the same image category until the subject indicated the target image by means of a button press. The distractors could easily be discriminated from the targets in prolonged viewing. Target and distractor were, however, often quite similar in texture and color, making the task quite difficult with the short exposures used here. The mask was chosen so that it would be similar to the target and distractor images, and so that its image statistics matched the typical spatial frequency fall-off exhibited by natural scenes [11,12]. This was achieved by drawing randomly positioned and sized rectangles and lines, whose colors were randomly chosen from the target or the distractor image. Presentation of the mask limits the amount of time available for analyzing the image and transferring information into short-term memory [24]. Twenty young students from the University of Tübingen served as subjects in this experiment.

the possibility that subjects simply notice a particular colored patch in the target image, which they later use for recognition. Rather, they are able to identify the structure of these briefly presented images. Therefore, the perception of structure and form defined by color seems to be a rapid process. At longer presentation durations, images presented in color were recognized better than those presented in black and white only when the testing was also done in color. Here, the advantage of color is presumably due to an enriched representation of the color images in short-term memory. Taken together, our results show that color helps the recognition of images both through coding and representation, and that these two processes can be dissociated in time. In other words, color helps us to recognize things faster and to remember them better.

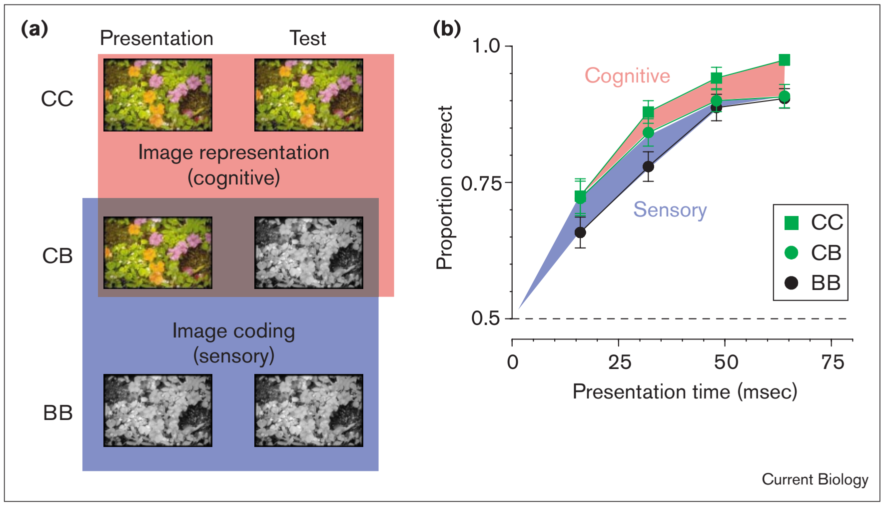
Visibility of natural colored scenes

There are several possible ways in which an advantage in coding might be achieved. A simple possibility would be that the color images possess higher visibility. Natural images are dominated by low spatial frequencies [11,12], and the sensitivity of the human visual system to colored low-spatial-frequency patterns is high. When expressed in terms of contrast delivered to the cone photoreceptors, sensitivity for chromatic patterns is in fact much higher than for luminance patterns [13]. The question is whether that advantage also holds for the contrast variations occurring in natural images. Contrast-detection thresholds were, therefore, measured for briefly presented (64 msec) colored and black and white images.

Figure 3a shows the proportion of correctly detected images as a function of the image contrast. Visibility increased with increasing contrast, and threshold performance was reached at a contrast of about 10%, that is, the luminance and color contrast of the original images was reduced by a factor of 10. Most importantly, there was absolutely no difference in performance for colored and for black and white images, indicating that the above differences in recognition were not simply due to the higher visibility of the colored images.

This is surprising in light of the high sensitivity of the human visual system to low-spatial-frequency chromatic variations [13]. As the natural images contain mostly low-spatial-frequency information, one would expect a similar advantage for their detection. We therefore decided to look at the distribution of contrasts in our images. Figure 3b shows the contrast in the long- and middle-wavelength-sensitive cones for a random sample of pixels from our color images (blue dots), as displayed on the monitor used. The directions of luminance and color are indicated by the black arrows in the diagram. The red squares indicate detection thresholds for low spatial frequency gratings [14], scaled so that the luminance threshold has a value of unity. Apparently, thresholds in the color direction are closer to the origin and are therefore lower. It can be seen that our images contain large variations along the luminance axis, but the average contrast in the color direction is lower by a factor of about 20–25 [15,16]. The advantage of the color system over the luminance system, because of its increased sensitivity, is far outweighed by the reduction in the naturally occurring color contrasts. Figure 3b also shows the results of spectroradiometric measurements of highly saturated fruit and vegetable objects (green circles). The colors we used in the images (blue dots) do

Figure 2



Results of the recognition experiment. **(a)** Images were presented either in color or in black and white, and were queried either in color or in black and white, resulting in four different conditions. For the sake of clarity, condition BC (presentation in black and white and testing in color) is not shown here or in the results; it was generally not different from the BB condition. For the black and white images, the intensities of the red, green and blue phosphors at any pixel were all set to the same value, which was chosen so that the luminance of each pixel was identical under both the colored and the black and white conditions. **(b)** The proportion of correctly recognized images as a function of presentation duration was averaged over all image categories. Green squares indicate trials for images presented and tested in color, filled black circles indicate trials in which the target images were presented and tested in black and white, and the filled green circles indicate targets presented in color but tested in black and white. At the short presentation duration of 16 msec, images presented in color were recognized more accurately than those presented in black and white, independently of whether their identification was tested in color or in black and white. At a longer presentation duration of 64 msec, images presented in color were recognized better than images presented in black and white, but only when the testing was done with colored images as well. Each data point is based on 240 trials, 12 from each of 20 subjects.

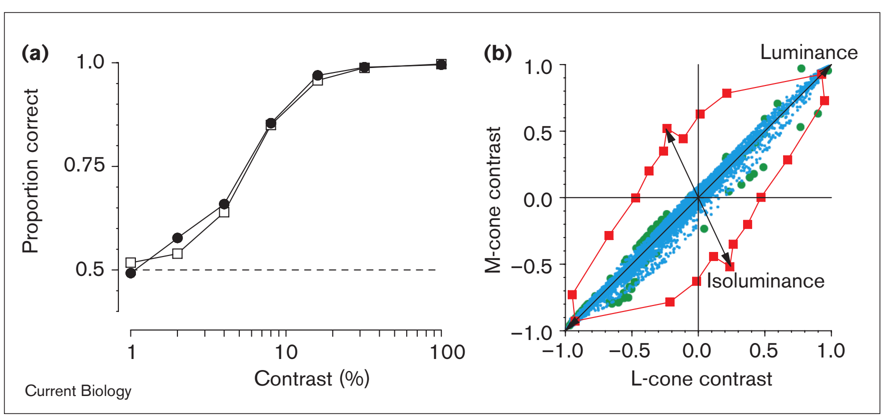
not exceed the naturally occurring contrasts. This excludes the possibility that color was inappropriately emphasized in the images we used.

An alternative mechanism for achieving an image-coding advantage might be color-based image segmentation. Several successful computer models for image segmentation based on chromatic information have recently been presented [17,18]. Psychophysically, color is highly useful in image segmentation [19], and its contribution seems to occur very rapidly [20], in agreement with the present results.

Conclusions

Our results show a clear and fast contribution of color to the recognition of natural images. There are at least two

Figure 3



Results of the detection experiment. **(a)** The proportion of correctly detected images as a function of image contrast. Each image was shown either in the top or bottom half of the monitor for 64 msec, followed by a mask that covered the whole screen. The subject simply had to indicate the location of the image. The contrast of an image was defined relative to the original image (100%). Contrast was then reduced by scaling the difference of each pixel with the mean color over the whole image ensemble. Open squares indicate trials in which the targets were presented in color, filled circles indicate trials in which the targets were presented in black and white. There was no difference in performance between images presented in color and images presented in black and white. Thirty-three subjects participated, including the 20 from the recognition experiment. **(b)** Cone contrasts for a random sample of pixels from the color images used in these experiments (blue points). For comparison, the green filled circles indicate cone contrasts of a variety of highly saturated fruit and vegetable objects, as measured using a spectroradiometer under natural daylight conditions. The red contour indicates threshold measurements (magnified by a factor of 250) for low-spatial-frequency stimuli [14]. The two arrows indicate the luminance and isoluminance directions in cone contrast space.

major ways in which color could support recognition. One is at an early level, where color adds one additional cue upon which image segmentation can be based. The other is at a later level, where color adds one more cue for the retrieval of information from memory. Previous experiments found evidence for both types of facilitation, which was seen as a contradiction. Humphrey *et al.* [21] proposed a high-level contribution of color to recognition, because a patient with visual form agnosia also benefited from color information, and performance for normal observers was higher for color, only when objects were presented in their natural color. On the other hand, Wurm *et al.* [22] found evidence for a low-level sensory contribution, as color improved object recognition irrespective of the diagnostic role of color for the identification of the object. Our experiments show that, for object recognition in natural scenes, color information contributes at both the sensory (coding) and cognitive (representation) levels of information processing. Furthermore, the traditional view of color information being processed slowly and independently of luminance information [23] is not tenable in the context of viewing natural scenes. Color and luminance are intermingled and used in combination with information about visual form to achieve a fast and unitary representation of the visual world in the brain.

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