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Color Categorical Perception

J. Richard Hanley*
Department of Psychology, University of Essex, Colchester, UK

Definition

Categorical perception (CP) occurs when discrimination of items that cross category boundaries is faster or more accurate than discrimination of exemplars from the same category. Categorical perception of color is observed when, for example, a green stimulus and a blue stimulus are more easily distinguished than two stimuli from the same color category (e.g., two different shades of green). Color differences in terms of discriminability can be equated across between-category and within-category comparisons by using the *Commision Internationale de L'Eclairage* (CIE) values. It is therefore important to note that superior cross-category relative to within-category discrimination is observed when the physical distance between cross-category items and the physical distance between within-category items are equivalent.

Categorical Perception Using a Two Alternative Forced-Choice Procedure

Categorical perception of color has been demonstrated many times using a two alternative forced-choice (2-AFC) procedure. In an experiment of this kind, participants view a colored patch for a short duration. Shortly afterward, the original item is displayed next to a distractor, and the participant has to indicate which of the two colored patches was presented a few moments earlier. Discrimination between the target and distractor is significantly more accurate when they belong to different color categories (e.g., green target and blue distractor) than when they come from within the same color category (e.g., target and distractor are different shades of green).

Categorical perception on the 2-AFC task has provided evidence for the existence of different color categories in different cultures [1]. For example, the Berinmo are a traditional hunter-gatherer culture in the upper Sepik region of Papua New Guinea who have a different set of basic color terms from speakers of English. Berinmo speakers showed significantly better discrimination of 32 cross-category items than 32 within-category items at the boundary between two Berinmo color categories (*nol* and *wor*) that do not exist for English speakers [1]. Conversely, English speakers did not show CP at this boundary. Most important, there was no evidence of CP at the boundary between green and blue for speakers of Berinmo whose language does not make this distinction. Such findings provide evidence against the idea that color categories are universal and exist irrespective of the color vocabulary that speakers have acquired during language development.

Hanley and Roberson [2] argued that CP in the 2-AFC task reflects the role of categorical codes in distinguishing targets from distractors. They proposed that, in principle, participants can perform the 2-AFC task using either categorical or perceptual information about the target item. The categorical code contains less information but may generally be easier to retain than the perceptual code. Targets and distractors can be more accurately distinguished when they cross a category boundary because they differ at both the categorical and the perceptual level. The categorical code cannot be used to distinguish targets and distractors from the same color category, however, so participants must rely entirely on the perceptual code. This account can readily explain the finding that CP for color was abolished when a verbal

*Email: rhanley@essex.ac.uk

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interference task was interposed between presentation of the target and the test pair [3]. Presumably, verbal interference disrupts participants' ability to generate or retain the category code, and so performance for both within- and cross-category targets relied on retention of a perceptual representation of the color of the target.

Hanley and Roberson [2] also reanalyzed the results of a series of studies that had demonstrated CP effects for color using the 2-AFC task. This reanalysis revealed that within-category performance was particularly weak when the target was a poor example of a color category and the distractor was a better exemplar. If, however, the target was a good exemplar and the distractor a poor exemplar, performance on within-category trials and cross-category trials was equivalent. Such an outcome is of considerable theoretical importance because it challenges the commonly held view that CP has a perceptual basis (e.g., [4]). According to this account, CP occurs because perceptual systems are fine-tuned by experience such that sensitivity to change is greater around category boundaries than it is to changes that occur within a category. Exactly the same perceptual discriminations are required for within-category trials in which performance is good (central target, peripheral distractor) as for those in which performance is poor (peripheral target, central distractor). Consequently, the advantage for central targets over peripheral targets, which forms the basis for CP in the 2-AFC task, cannot reflect greater perceptual sensitivity for central targets.

Why is performance so poor on the 2-AFC task when targets are peripheral examples of a color category? Hanley and Roberson [2] argued that the poor exemplars in these studies were less likely to be classified as category members when they appeared at test alongside a good exemplar than when they appeared by themselves at presentation. The likely outcome is a mismatch between the way in which a peripheral target is categorized when it is originally presented and the way it is classified at test. A mismatch of this kind will lead to poor performance on the 2-AFC task because the categorical code now provides misleading information about the identity of the target color. This explanation is consistent with the findings that classification of an exemplar at the center of a color category was unaffected by the presence of a peripheral category member [5]. But, crucially, when a poor exemplar appeared alongside a central exemplar, the poor exemplar was frequently assigned a different category label from the one it was given when it appeared on its own. Similar effects have been observed in other domains and have been termed "category contrast effects" [6].

Consistency of categorization is crucial to the account of CP for color in the 2-AFC task suggested by Hanley and Roberson [2]. For within-category pairs, it might appear that a categorical code could not possibly distinguish target from distractor. However, it follows from the category contrast effect that when the target is a central exemplar and the distractor is a poor exemplar, the distractor is likely to be given a different categorical label from the target. Hence, Hanley and Roberson argued that good performance in the 2-AFC task when the target is a central exemplar occurs because target and distractor can often be accurately distinguished on the basis of the categorical code. It also follows from the category contrast effect that performance will be poor on within-category trials when the target is a peripheral exemplar. For example, a greenish-blue boundary target may be categorized as "blue" when it appears on its own. However, the presence at test of a distractor that is a good example of "blue" means that the peripheral "blue" target will sometimes elicit a different category label ("green") at test. The outcome will be that the category label given to the target at encoding is elicited at test only by the distractor, which is likely to be selected in preference to the target as a consequence.

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Categorical Perception in Visual Search Tasks

Even though test stimuli are presented relatively soon after the target has been removed, performance on the 2-AFC task necessarily depends on a memory code for the target color. Recent studies have also found CP for color in visual processing tasks where the memory component is minimized. For example, Gilbert et al. [7] presented an oddball stimulus in the presence of a series of identically colored background items. Even though the size of the physical difference between the oddball and the background items was held constant, participants were quicker to identify the oddball when the background items belonged to a different color category from the oddball than when oddball and targets were different exemplars of the same color category. Brown et al. [8] have failed to replicate these findings and claim that color discrimination on this task is determined by perceptual rather than categorical differences. Nevertheless, similar results to those reported by Gilbert et al. [7] have been reported in several studies [9–11]. For example, Franklin et al. [10] adapted the task by presenting participants with a colored background and asking them to indicate as quickly as possible which side of fixation a differently colored patch suddenly appeared against this background. Response times were significantly faster when background color and patch came from different categories than when the patch and background were different exemplars of the same category.

In some languages such as Russian, Greek, and Korean, additional color categories exist that are not present in English. For example, *siniy* (dark blue) and *goluboy* (light blue) are distinct basic color terms for speakers of Russian, and *yeondu* (yellow-green) and *chorok* (green) are distinct basic color terms for speakers of Korean. An important question is whether CP can be observed in visual search tasks at boundaries between color categories of this kind. This issue has recently been investigated with speakers of Russian [11] and with speakers of Korean [9]. Russian participants showed CP at the boundary between *siniy* and *goluboy* in the visual search task [11]. Conversely, English speakers, who would call all of these stimuli "blue," did not show the same cross-category advantage at the siniy-goluboy boundary. Korean participants showed CP at the boundary between *yeondu* and *chorok*, but no evidence of CP was shown by native English speakers at this boundary [9]. These findings reinforce the claim that color categories are determined by the color vocabulary that speakers acquire during language development.

Two sets of additional findings have provided information about the precise point at which categorical codes influence color categorization in this experimental paradigm. First, CP was not observed in perceptual tasks when participants carried out a concurrent verbal interference task [7, 11]; under verbal suppression, all equally spaced separations of color were equally easy to discriminate regardless of the presence of a color boundary. Second, Gilbert et al. [7] and Roberson et al. [9] reported that the CP effect was only found for colors that were presented in the right visual field, which is presumed to preferentially access language-processing areas in the left hemisphere. No difference between within-category and between-category pairings of targets and distractors was observed for colors presented in the left visual field, which gains preferential access to the nonverbal right hemisphere. Gilbert et al. [7] also showed that CP was found only when stimuli were presented to the left hemisphere of a patient in whom the corpus callosum (the structure that connects the two hemispheres of the brain) had been surgically severed.

The speed with which categorical information is accessed in these visual processing tasks suggests that there is rapid automatic retrieval of a categorical code when a colored stimulus is presented. Nevertheless, the results from these tasks can be readily explained in terms of Hanley and Roberson's [3] dual code account of categorical perception. Assume that decisions about whether a target and a background item are the same color are taken on the basis of either a right hemisphere perceptual code or a left-hemisphere categorical code and that when the two codes conflict, accuracy and speed will be reduced. Automatic activation of color category names should therefore slow judgments about whether, for example, two different shades of blue are different. This is because the categorical information that they are the same is

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in conflict with the perceptual information that they are different. Decisions for items from different categories (e.g., blue and green) will be quicker and more accurate because both the categorical and perceptual codes provide evidence that is consistent. When the left-hemisphere language system is suppressed by verbal interference, or is not accessed because information is presented directly to the right hemisphere, the categorical code is not generated, and there is never any source of conflict with the perceptual code. Hence, without the language system, there is no advantage for comparisons that fall across category boundaries. Such an account can also explain why an unpredicted improvement in within-category performance has been observed when verbal interference abolished CP for color [7, 11]. Within-category performance cannot be delayed by a mismatch between the categorical and perceptual codes if a categorical code is not generated.

Categorical Perception and Event Related Potentials (ERPs)

Categorical effects for color have also been demonstrated in a paradigm that measures event-related potentials [12]. Participants were asked to look at a display containing a series of colored patches and respond as soon as they saw a cartoon character that appeared infrequently among the patches. The key manipulation was that the patches changed color; sometimes the color category changed, and sometimes the shade changed but the color category remained the same. These color changes took place at a different time from the appearance of the cartoon figures. Color processing was incidental because participants were never asked to pay any attention to color when making their responses to the appearance of the cartoon figures. The latency of the response in the ERP signal to cross- versus within-category color changes was investigated. Crucially, significantly earlier ERP peak latencies were observed when the color change involved a different color category (195 ms) than when the change involved a different exemplar from the same color category (214 ms). Such findings make it clear that information about color categories is available within the brain at a very early stage of visual processing.

Thierry et al. [13] employed a similar task to native Greek speakers. The Greek language makes a categorical distinction between light blue (*ghalazio*) and dark blue (*ble*). Thierry et al. investigated the strength of the ERP response to unexpected changes from *ble* to *ghalazio* and reported a difference in the amplitude of the ERP. They referred to the response to such changes as a visual mismatch negativity effect (VMMN). The Greek speakers' ERP responses were significantly weaker when there was an unexpected change from light to dark green that did not cross a category boundary for either Greek or English speakers. Conversely, speakers of English did not show a stronger VMMN response to changes from *ble* to *ghalazio* than to changes from light to dark green. Athanasopoulos et al. [14] subsequently found that the signal strength of the VMMN response shown by their Greek participants when *ble* changed to *ghalazio* was negatively correlated with their length of stay in the UK. Once again, these findings emphasize the close link between visual processing of color categories and participants' linguistic experience.

Mo, Xu, Kay, and Tan [15] investigated the strength of the VMMN effect when the color change occurred in only the right (RVF) or in only the left visual field (LVF). They reported significant VMMN effects in both hemifields. Like Thierry et al. [13], Mo et al. found a stronger VMMN when a color change crossed a category boundary (in this case the boundary between blue and green) than when there was a change between two equally distinct exemplars of the same color category (e.g., different shades of green). Crucially, however, this categorical effect was observed only when the color change occurred in RVF; in LVF the strength of the VMMN was equivalent for within- and between-category changes.

In the ERP data, differential responses to cross- versus within-category pairs of stimuli appear between 100 and 300 ms after stimulus presentation. Such rapid processing of categorical information has led to

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suggestions that CP in perceptual tasks of this kind may reflect activity at a site in visual cortex rather than in language areas [12]. These findings are clearly consistent with the claim that CP effects for color can sometimes be genuinely perceptual and may arise from increased perceptual sensitivity at color category boundaries. It is, however, difficult to reconcile this claim with the finding that even the early and automatic categorical color effects that are detected by ERPs are lateralized to the left cerebral hemisphere [15]. Furthermore, the published studies that employ these ERP tasks have, to date, only reported cross-category versus within-category contrasts. Exactly the same perceptual discriminations are required regardless of whether the color change on within-category trials is from a good category member to a peripheral category member or vice versa. It remains to be seen whether the ERP signal is equally weak in both these situations relative to the ERP signal generated by a color change that crosses a category boundary. It is therefore unclear whether the asymmetry of within-category performance found consistently to cause CP in 2-AFC tasks [2] generalizes to visual mismatch negativity in ERP signals. If color CP effects in these visual processing tasks are also the result of a category contrast effect, it would be difficult to see how an explanation of the ERP data that is based on perceptual sensitivity could reasonably be maintained.

Cross-References

► Berlin and Kay Theory
► Infant Color Categories

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