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Infant Color Categories

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Synonyms

Prelinguistic color categorization/categorical perception

Definition

A response to color in infancy that indicates that infants can divide the continuum of color into discrete groups.

Key Principles and Concepts

Although humans can discriminate millions of colors, language typically refers to color using a limited number of discrete categories (e.g., *red*, *green*, *blue*). Color categories are not only present in language (color terms), they are also present in "thought." For example, at least under some circumstances, adults' perceptual or cognitive judgments of color (e.g., color memory, search, or similarity judgments) are affected by whether colors come from the same or different linguistic color categories [see Hanley]. There has been considerable debate on the origin of color categories and on the extent to which color categories are arbitrarily constructed through language (see ref. [1] for review). To establish whether there is a nonlinguistic route to color categorization, prelinguistic infants' response to color has been investigated. This has provided converging evidence that infants' perceptual or cognitive judgments of color can also be affected by whether colors come from the same or different adult color categories. This suggests that color categories are present even in infancy and that even infants, on some level, can parse the continuum of color into discrete groups.

Methods and Examples

Investigations of adults' categorical response to color have used a range of experimental tasks that provide behavioral or electrophysiological measures of color memory, color search, or chromatic change detection. In these studies, chromatic differences for same- and different-category color pairs are equated, and an influence of the categorical relationship of colors on task performance is assessed. An equivalent approach has been taken to investigate infant color categories. Many of the studies of infant color categories have used the well-established method of *habituation* to assess the influence of categories on infants' response to chromatic novelty. This method involves the repeated presentation of a stimulus (or set of stimuli) until infants' looking time at the stimulus declines (habituation). Then, during a test phase, novel and original stimuli are presented and

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looking time is recorded. Greater looking to the novel stimulus relative to the original stimulus during the test phase (novelty preference) indicates that the infant is, on some level, treating novel and original stimuli as different. A lack of longer looking at the novel stimulus relative to the original indicates that the infant is, on some level, treating novel and original stimuli as equivalent. The degree of novelty preference can therefore be compared when novel and original stimuli from the same or different categories. Greater different- than same-category novelty preference when chromatic differences are equated would indicate an influence of categories on infants' perception or cognition. In addition, categorization can be broadly defined as the treatment of discriminably different stimuli as equivalent (e.g., [2]). Therefore, a lack of novelty preference when infants can discriminate between novel and familiar stimuli becomes a clear marker of categorization. This method has provided overwhelming evidence for infant categories, for a wide range of categories such as phonemes, facial expressions, animals, spatial locations, and orientation (e.g., see [2]).

For color, multiple studies have found a categorical response in infants at 4 months using the habituation method (e.g., [3–6]). Bornstein et al. [3] tested infants at 4 months using monochromatic lights, with the difference between the original and novel stimulus equated in wavelength. Infants responded to a change in stimulus that crossed blue-green, yellow-green, and yellow-red category boundaries, but not to a change in stimulus within these categories. There was one exception to this: when infants were habituated to a red wavelength, their interest in the original red stimulus continued at test, most likely due to the salience of red in infancy. Apart from this, infants' recognition of novelty in hue was completely categorical, and Bornstein et al. concluded that infants categorize blue, green, red and yellow hues at 4 months. Two further studies also provide evidence of a categorical response to color in infants, finding that 4-month-olds fail to recognize the novelty of a color when original and novel colors are from the same blue or green category [4] or from the same red or blue categories after a 5 min delay between habituation and test [5]. In addition, a fourth study indicates that 4-month-old infant's response to chromatic novelty is also categorical across blue-green, red-pink, and blue-purple category boundaries, when same- and different-category colors are equated in color metrics such as the Munsell color system and CIE (L*u*v*, 1976) color space [6].

Therefore, a categorical response to color in infancy has now been found in multiple habituation studies, for over 25 different stimulus pairs taken from three different color metrics, and with different versions of the habituation task. In all of these studies, the same-category chromatic differences are known to be discriminable to infants at 4 months. Infants at 4 months are able to discriminate same-category chromatic differences of an equivalent size when tasks do not involve color memory (e.g., color search: [7, 8]), and the same-category chromatic differences were all much greater than chromatic discrimination thresholds at 4 months. In fact, some of the same-category stimulus separations in Bornstein et al. investigation were as much as 20 times larger than the estimated just-noticeable difference for a 4-month-old (see [6]). Even when a luminance difference is intentionally added to maximize the difference between novel and original stimuli [6], 4-month-old infants still fail to respond to the novelty of a color from the same category as the original. Infants' pattern of responding to color on habituation tasks therefore fits the classic definition of categorization that "discriminably different stimuli are treated as equivalent" (e.g., [2]). These studies provide a parallel to adult studies which have used an X-AB task. The X-AB task requires participants to encode an original color and then distinguish it from a novel foil after a delay. Adults are poorer at identifying the original color when the original and foil are from the same category than when they are from different categories. Infants' pattern of response on habituation tasks is equivalent to this, as they are also poorer at distinguishing between original and novel same- than different-category colors at test. In fact, infants are even more categorical in their response than adults as, at least under some conditions, they fail to distinguish between the original and novel same-category colors at all.

Another method which has been used to investigate both adult and infant color categories is the event-related potential (ERP) technique. This involves measuring electrical activity from the scalp, which is then time locked to an event such as stimulus onset. Event-related potentials have been measured on a visual oddball task which is commonly used in ERP studies of both adult and infant categorization. The visual oddball task involves the frequent presentation of one stimulus (the standard) interspersed with the infrequent presentation of other stimuli (the deviants), and ERP components for standard and deviant stimuli are compared for evidence of change detection. For adults, the categorical relationship of standard and deviant colors affects the latency and amplitude of several ERP components elicited in response to the stimuli. For example, different-category deviants elicit ERP components that peak earlier or are of greater amplitude than same-category deviants, indicating quicker and greater detection of different- than same-category chromatic change (see [9] for review). Category effects in ERPs on a visual oddball task have also been found in infancy [9]. Even at 7-months, the categorical relationship of standard and deviant colors affected infants' ERP components. Category effects were found in ERP components thought to index recognition memory (slow waves) and attentional allocation (negative central). For both, the different-category deviant elicited an ERP component that was more negative than that elicited by the standard color, yet the same-category deviant did not. These findings indicate that, within the context of the frequent repetition of a color, an infrequent different-category color will elicit greater attentional allocation and will be seen as more novel than the frequent color, whereas a same-category infrequent color will not. As in the habituation studies, the same-category colors were discriminable to infants at 7 months, and therefore the equivalence of the same-category deviant and standard in ERP components of attention and memory indicates electrophysiological markers of infant color categorization. Due to the time course of the negative central ERP component, Clifford et al. study also suggests that infants register the categorical status of a color from as early as 250 ms poststimulus onset. These findings are in line with other ERP studies of categorical responding in infancy, such as phoneme categorization and category learning of cats and dogs (see [9]).

Chromatic search tasks have also been used to investigate infant color categories. In adult studies that have used these tasks, participants are required to search for a colored target that is either from the same or a different category to the colored distracters or colored background. When same- and different-category colors are equated in CIE (L*u*v*, 1976) or Munsell color metrics, at least under some conditions, adults are faster or more accurate at searching for targets amongst different- than same-category distracters or backgrounds. The influence of color categories on infants' color search has been investigated by measuring 4–6-month-old eye movements to colored targets presented on colored backgrounds. Infants are significantly faster at fixating a colored target [7] and at initiating an eye movement to a colored target [8] when presented on a different- than same-category colored background. In these infant studies, the chromatic difference between the target and background was equated for same- and different-category color pairs in CIE L*u*v* color space yet are also closely equated when stimuli are converted to the MacLeod-Boynton cone excitation color space. Franklin et al. [8] found this effect of categories on infants' target detection when the target was presented to the left visual field, but not to the right visual field, potentially suggesting that there is a right hemisphere lateralization of categorical perception of color in infancy. This right hemisphere lateralization contrasts with reports of left hemisphere lateralization in the adults' category effect (see [1]), and it appears as though a right-to-left hemisphere switch occurs around the time of color term acquisition [10]. However, these effects have so far only been tested for in infants across the blue-green category boundary, and recent studies also report a lack of hemispheric lateralization for

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the effect in adults under some conditions (e.g., [11]). Further research is therefore needed to establish the nature of these effects in both infants and adults and the conditions for the pattern of hemispheric lateralization.

Negative Findings

There is only one published study which fails to find a categorical novelty response in infants [12], and that study tested for a categorical response across the red-orange category boundary using a task which determined whether a novel color "popped out" amongst six instances of a color to which infants had been familiarized. This could indicate that infants do not respond categorically across the red-orange boundary or that the novelty response is not categorical under conditions of "pop out." There may well be conditions under which infants' responding is not categorical, and as for adults, the relative strength of the categorical and physical code may depend on cognitive demands. However, it has been argued that an unintended category boundary for one of the same-category stimulus pairs, and the use of an inappropriate illuminant, renders the findings of Gerhardstein et al. unsafe [13]. A second unpublished study has been cited as evidence for a lack of replication of an infant category effect across the blue-green boundary. However, the habituation task that was used failed to detect any response to color in the infants at all, most likely due to particular parameters of the habituation task (e.g., a change from central to peripheral stimulus presentation at test could have detracted attention from the change in color). Therefore, as there was no response to color at all, a categorical effect could not be assessed (see [14] for further discussion). These negative findings, which should be considered as unsafe, are outweighed by the converging behavioral and electrophysiological evidence for a categorical response to color in infancy. The finding of infant color categories has now been replicated across multiple color category boundaries, using multiple tasks and color metrics, and by several independent research teams.

Alternative Explanations

As outlined above, there is converging evidence that, at least under some conditions, infants' response to chromatic novelty or recognition memory can be completely categorical. Potential alternative explanations for infants' response to color in these studies have been considered and ruled out. First, a priori hue preferences are unable to account for the findings as studies have controlled for these (see [14]). For example, same-category stimulus pairs have been sampled from both sides of the category boundary (e.g., [3, 6]), a priori preferences have been recorded and shown not to account for infants' response (e.g., [6]), and control tasks have also been included (e.g., [9]). Second, potential inequalities in the color metric are unable to account for infants' response to color. As for studies of adult color categories, there is an issue about which color metric is appropriate to equate same- and different-category colors: using a physical metric (e.g., wavelength), a perceptual metric such as Munsell or CIE (L*u*v*), or a cone-opponent color space (e.g., MacLeod-Boynton color space). Importantly, infant color categories appear to transcend this metric issue. Infants' pattern of response is identical across studies which vary in the color metric used. Additionally, at least under some conditions, infants' novelty response to color appears completely invariant to the color metric, as distances in any of these metrics do not predict the degree of infants' chromatic novelty preference or change detection. Infants treat same- but not different-category chromatic differences as equivalent on habituation or visual oddball tasks, irrespective of the size of the same-

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category chromatic difference. Only the categorical relationship between stimuli can account for this pattern of response.

Theoretical Questions and Future Directions

The converging evidence for infant color categories strongly suggests that there is a nonlinguistic route to parsing the continuum of color into discrete groups. However, there is also convincing evidence that the influence of color categories on adults' cognition and perception is dependent on language and that different languages also vary in how they divide up the color spectrum [see Roberson]. This raises two sets of challenging questions for future research to consider and address. First, what is the relationship between prelinguistic and linguistic color categories? Why do some languages not have color terms for categories that infants have? For example, many of the world's languages do not have separate terms for blue and green, yet infants appear to form separate categories for these. The answer to this question may be in the analysis of the World Color Survey [see TBA]. Multiple analyses of the World Color Survey strongly suggest that, despite variation in color lexicons, there is also striking commonality in how the world's languages divide up the color spectrum. For example, the centers of color categories across languages tend to cluster around particular points in the color space, with distinct clusters for "blue" and "green." It has therefore been suggested by several groups that there are perceptual constraints on how categories form in color lexicons (see [1]). Therefore, although not all languages have separate terms for blue and green, there appears to be a common pressure in the world's color lexicons for separate categories of blue and green to form. One possibility is that this commonality arises because infant color categories partially constrain the world's color lexicons, while local variation arises due to the additional influence of culture and communication [1].

Alternatively, infant color categories and those in language could operate independently from each other but could have similar organizing principles. This raises the question of what happens when prelinguistic and linguistic color categories converge when color terms are learnt. What are the mechanisms of the switch from a nonlinguistic to a language dominant division of the color spectrum? How do prelinguistic color categories affect color term acquisition? The presence of infant color categories strongly suggests that any difficulty that children have in learning color words is unlikely to be due to a lack of category structure but rather provides support for the argument that there are general attentional, conceptual, and linguistic constraints that make learning color words difficult relative to nouns, but not other adjectives (see [15]). However, it is theoretically possible that color term learning may be more difficult for lexicons which map less well onto the prelinguistic category structure that is there in infancy.

Second, what are the organizing principles of infant color categories? Where do infants get their category structure from? Several theories have been proposed to identify the organizing principles of color categories. For example, it has been proposed that color categories derive from (i) the clustering of colors taken from surfaces in the natural chromatic environment; (ii) reflection properties, with some colors (those that correspond to the unique hues) reflecting incoming light in a much simpler way than others; or (iii) an irregularly shaped perceptual color space combined with basic principles of categorization (see [1]). None of these organizing principles rely on language, and all are contenders for explaining how infants are able to categorize color even before color terms have been learnt. Importantly, color categories may not be inbuilt into our visual system but rather could be a cognitive response to inequalities in our visual system's processing of color. Some hues could be more salient than others, for example, due to having greater maximum levels of

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saturation or different reflection properties. This could lead to some colors being more informative than others, and inequalities such as these could provide structure for cognition when categorizing. The actual categorical response to color in infants could therefore come from an interaction of perceptual inequalities in color and a general cognitive strategy to categorize. It is well known that categorization is a core part of infant cognition and is essential in helping infants to navigate an uncertain world (e.g., [2]). If color categories do result in part from general cognitive strategies, differences between humans and animals in the extent of the categorical response to color could arise due to differences in cognition, even if color vision is similar (e.g., baboons; see Weber and Changizi).

These questions on how infant color categories relate to those in language, and on the organizing principles and underlying mechanisms of infant color categories, provide clear direction for future research. Investigations which empirically address such questions will resonate beyond color and will have implications for fundamental questions on how categories are formed, how categories in language and thought interact, and how categories are expressed in the brain.

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