5. The analytical gas chromatograph was a Varian 1200, with a flame ionization detector. The preparative model was an Aerograph 700, with a thermal conductivity detector. Mass spectra were obtained with a Hitachi-Perkin-Elmer RMU-6E coupled to a Varian Aerograph 204 gas chromatograph. Optical rotation measurements were made with a Perkin-Elmer 141 polarimeter.
6. No attempt was made to determine the limit of error in the optical rotation measurements since not the order of magnitude, but only the sign of the rotation was considered important in our study.
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8. Supported in part by grant BMS 73-01599 from the National Science Foundation.

21 July 1975; revised 14 October 1975

## The Categories of Hue in Infancy

Abstract. *Infant looking time was monitored during habituation to the repeated presentation of a wavelength stimulus selected from one basic adult hue category and after a change in stimulation. Recovery from habituation was greater to a wavelength selected from an adjacent hue category than to a wavelength from the same category even though these two stimuli were equally distant (in nanometers) from the habituation wavelength. Differential responding evidenced infants' categorical perception of hue; that is, infants see the physically continuous spectrum as divided into the hue categories of blue, green, yellow, and red. These results help to resolve the long-standing controversy surrounding the primacy of perception over language in the organization of hue.*

We have found that 4-month-old infants respond to differences in wavelength as though they perceived categories of hue—blue, green, yellow, and red. That is, infants responded differently to two wavelengths selected from adjacent adult hue categories (for example, blue at 480 nm and green at 510 nm) but did not respond differently to two wavelengths separated by the same physical distance but selected from a single adult hue category (for example, blues at 450 nm and 480 nm).

Modern school children still paraphrase Newton's original observations on the categories of hue in the spectrum (*1*).

The Original or primary colours are, *Red*, *Yellow*, *Green*, *Blew*, and a *Violet-purple*, together with *Orange*, *Indico*, and an indefinite variety of Intermediate gradations.

Substituting narrow monochromatic radiation for prism-dispersed sunlight, and psychophysical techniques for introspection (*2*), modern research has confirmed the relationship between wavelength and color naming given in Newton's original experiments. Wavelengths are usually described by one or two primary hue names (Fig. 1). Color-naming functions are roughly characterized by plateaus—wavelength ranges which form categories where a single hue term predominates—and by boundaries between the plateaus. Although the physical dimension is continuous, the psychological structure is discontinuous. Moreover, it has been argued that discrimination is typically poor nearer the center of plateaus (these wavelengths look the same and, hence, tend to be called by the same name), but discrimination is good at boundaries between hues (as chromatic distinctions become clearer, color names change) (*3*). The categorical perception of hue may have a biological basis. De Valois (*4*), for example, has demonstrated that discrimination of wavelength in the macaque (which has demonstrated color vision identical with normal human adult trichromats) is a function of chromatic analysis by thalamic neural tissue. Furthermore, Bornstein (*5*) has matched the results of cross-cultural studies on the designation of hue category centers to the sensitivity maxima of these same neural cells. Finally, the observation that at least two infrahuman species (*6*) see hues categorically makes the assumption of a biological basis for qualitative chromatic distinctions more plausible than the alternative assumptions about learning and language.

These logical, psychological, neurological, and ethological considerations led us to hypothesize that very young human infants would see the physical spectrum in a categorical fashion much like that of adults. To test this hypothesis, we made use of the fact that babies look less and less at a visual stimulus that is repeatedly presented (*7*). At the end of the so-called habituation phase, a test stimulus perceived by the child as dissimilar from the first stimulus produces increased looking (dishabituation); if, however, the child sees the test stimulus as similar to the first stimulus, looking time remains low (continued habituation).

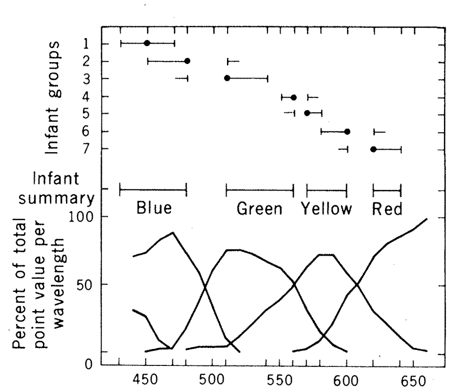


Fig. 1. (Upper panel) Results for seven infant experimental groups. Dots stand for habituation stimuli, vertical bars for category and boundary stimuli; a horizontal connection indicates a lack of difference in mean looking times between wavelengths, and a gap indicates, by comparison, a statistically significant difference (see Table 1) (*18*). The summary gives ranges of wavelengths responded to as similar by infants as well as ranges of probable transition between hues. (Lower panel) Adult color-naming functions replotted after Boynton and Gordon (*14*).

In our experimental situation, infants were shown a given wavelength of light (habituation stimulus, HS) (*8*) for fifteen 15-second trials followed by a series of nine 15-second test trials. Intertrial intervals averaged 7.5 seconds. The test series consisted of three blocks each containing three randomized stimuli: HS and two physically different stimuli, one selected from the same category as HS (category stimulus, CS) and one selected from a category adjacent to HS (boundary stimulus, BS). In this design infants serve as their own controls since they are continuously probed in the test series for their responses to HS (*9*).

Our main hypothesis was that the basic hue categories (blue, green, yellow, and red) and the boundaries between categories (blue-green, green-yellow, and yellow-red) common to adults would exist in infants. Consequently, we chose wavelength stimuli to straddle the color-naming boundaries (HS and BS) or to fall wholly within a single adult color-naming category (HS and CS). Moreover, BS and CS in each test sequence were separated by equal physical distances (in nanometers) from HS. Thus, for example, HS for experimental group 2 was a 480-nm light which adults perceive as mostly blue, CS was a 450-nm light perceived by adults also as blue, and BS was a 510-nm light perceived by adults as mostly green. Consequently, if babies look longer at one or another of the test stimuli of 450, 480, and 510 nm, then we would have inferential evidence about the infants' perception of the similarities and qualitative categorization of these wavelengths. Each boundary was explored by two groups of infants—for one group HS and CS were drawn from the category on the short-wavelength side of the boundary (for example, experimental group 2) and for a second group HS and CS were drawn from the category on the long-wavelength side of the boundary (for example, experimental group 3). Thus, HS in group 3 was 510 nm, BS was 480 nm, and CS was 540 nm.

Eight groups of ten healthy, full-term 4-month-old Caucasian infants were seen.

Table 1. Stimuli and results for infant groups. $N$, number of males (M) and females (F). Mean looking times and individual comparisons are explained in (*18*). Abbreviations: HS, habituation stimulus; CS, category stimulus; BS, boundary stimulus; NS, not significant. BS was compared with HS and CS.

| Group | N | | Age in days (mean ± S.D.) | Mean looking times (seconds) for each stimulus (nanometers) tested | | | | | | P |
|---|---|---|---|---|---|---|---|---|---|---|
| | M | F | | BS | Time | HS | Time | CS | Time | |
| | | | | *Blue plateau* | | | | | | |
| 1 | 5 | 5 | 129 ± 14.0 | 430 | 5.0 | 450 | 4.2 | 470 | 4.5 | NS |
| | | | | *Blue-green boundary* | | | | | | |
| 2 | 5 | 5 | 124 ± 9.8 | 510 | 7.3 | 480 | 5.7 | 450 | 5.8 | < .001 |
| 3 | 5 | 5 | 122 ± 6.8 | 480 | 7.0 | 510 | 5.0 | 540 | 4.0 | < .001 |
| | | | | *Green-yellow boundary* | | | | | | |
| 4 | 5 | 5 | 129 ± 6.8 | 570 | 6.6 | 560 | 3.9 | 550 | 4.7 | < .001 |
| 5 | 5 | 5 | 128 ± 6.4 | 560 | 6.2 | 570 | 3.3 | 580 | 4.4 | < .001 |
| | | | | *Yellow-red boundary* | | | | | | |
| 6 | 5 | 5 | 120 ± 5.9 | 620 | 6.0 | 600 | 4.6 | 580 | 4.2 | < .01 |
| 7 | 5 | 5 | 118 ± 4.7 | 600 | 4.5 | 620 | 6.1 | 640 | 5.4 | < .05 |
| | | | | *Control* | | | | | | |
| 8 | 4 | 6 | 129 ± 11.7 | 630 | 4.3 | 630 | 4.8 | 630 | 5.0 | NS |

Infants looked at the stimuli across the boundaries blue-green, green-yellow, and yellow-red as well as at stimuli expected to fall fully within the four basic adult categories of hue (Table 1). Infants were assigned randomly to groups, with the exception that infants within each group were matched for sex as well as age (*10*).

The upper panel of Fig. 1 shows that infants perceived a blue to green boundary between 480 and 510 nm, and parallel patterns of findings indicated hue boundaries for infants from green to yellow and from yellow to red (*11*). Detailed analysis of these results reveals two additional aspects of the data (Table 1). First, as is common among adults (*5*), infants (group 1) did not respond to violet (430 nm) as though it were a unitary sensation and wholly different from blue (450 to 470 nm). Second, direction in looking time dishabituation for group 7 is reversed. Long wavelengths have been found to exert a singularly strong influence over infant attention (*12*); it may be, therefore, that sustained looking at 620 nm and 640 nm relative to 600 nm can best be attributed to infants' preference for red. Finally, a control group (experimental group 8) that received the same stimulus throughout both the habituation and test phases (630 nm for 24 consecutive trials) showed no statistical differences among the means of the three test-trial blocks (*13*). In comparison with our observations on infants, the lower panel of Fig. 1 reports Boynton and Gordon's observations of color naming in adults (*14*). In summary, our results indicate that the boundaries and categories for four basic hues are much the same for 4-month-old infants as they are for adults.

The results of this study have several implications. First, human infants group visible wavelengths into hue categories much like the adult's at an earlier age than had been thought in the past and long before the onset of language or formal tuition. These results, then, demonstrate that infants have color vision. Second, the parallel existence of categories in infants and adults, for hue as for speech (*15*), is significant for understanding what organization of the environment the child brings to language. Finally, these results help to resolve an anthropological-linguistic question (*16*, *17*) which dates back to Gladstone (*16*): In color, does perception influence language or language influence perception? The fact that the basic hue categories of infants match those of adults strongly favors the primacy of perception.

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### References and Notes

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3. Wavelength discriminability and hue naming do not coexist in a perfectly correlated way. However, there exist evidence and expert opinion that a high correlation between plateaus and regions of poor discriminability exists in both pigeon [A. A. Wright, *Vision Res.* **12**, 1447 (1972)] and man [W. D. Wright, *Researches on Normal and Defective Colour Vision* (Mosby, St. Louis, 1947); L. C. Thomson, *Opt. Acta* **1**, 93 (1954); G. Ekman, *ibid.* p. 64; G. Jacobs and H. Gaylord, *Vision Res.* **7**, 645 (1967); D. P. Smith, *ibid.* **11**, 739 (1971); and B. Graham, M. Turner, D. Hurst, *J. Opt. Soc. Am.* **63**, 109 (1973)].
4. R. L. De Valois, I. Abramov, W. R. Mead, *J. Neurophysiol.* **30**, 415 (1967); see also A. Cerf-Beare, [*Percept. Psychophys.* **13**, 546 (1973)].
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7. L. B. Cohen and E. Gelber, in *Infant Perception*, L. B. Cohen and P. Salapatek, Eds. (Academic Press, New York, in press).
8. Chromatic flux was generated by a monochromator system [M. H. Bornstein and N. Cox, *Behav. Res. Methods Instrum.* **6**, 31 (1974)], and calibrations were completed as describe M. H. Bornstein [*J. Exp. Child Psychol.* **19**, 401 (1975)]. Lights were equated in luminance (3.4 $cd/m^2$) by Judd's modification of International Commission on Illumination (Commission Internationale de l'Eclairage, C.I.E.) Standard Observer luminosity [D. B. Judd, *C.I.E. Proc.* **1**, 11 (1951); for details see G. Wyszecki and W. S. Stiles, Eds., *Color Science* (Wiley, New York, 1967), p. 436]. D. Y. Teller and D. R. Peeples [papers addressed to Association for Research in Vision and Ophthalmology, Sarasota, Fla. (April 1974 and 1975)] have presented evidence that relative spectral sensitivities for infants and adults (CIE) do not differ significantly at medium and long visible wavelengths; our use of Judd's modification of CIE would tend to reduce further potential differences at short wavelengths. Stimuli were circular (88.9 mm diameter), subtended approximately 10° of visual angle at the infant's eye, and were presented against a matte black surround.
9. This technique is a test of coding or categorization and not of discrimination per se, since test stimuli (HS, CS, and BS) and the habituation stimulus (HS) were never simultaneously present.
10. We included in our analysis only children whose looking time (means) on the last three trials of the habituation phase was less than 80 percent of the mean of the highest earlier three-trial period of the habituation phase. That is, we thought some reasonable reduction of looking at HS was requisite to successful testing of the habituation-dishabituation paradigm. Consequently, children who were included showed statistically significant decrements in looking time over the course of habituation ($P < .001$ in all groups).
11. In addition, two infant groups ($HS_s$ = 590 and 600 nm) responded equally to wavelengths between 580 and 610 nm.
12. M. H. Bornstein (*8*). The two reds in group 7 (620 and 640 nm) are predictably, statistically, and reliably separable from 600 nm.
13. This control, along with built-in intraobserver controls, eliminates explanations of these results based on fluctuations of attention.
14. R. M. Boynton and J. Gordon (*2*). In their experiment, subjects were allowed to use one or a combination of two basic color terms—red, yellow, green, or blue—to describe a variety of spectral lights seen in Maxwellian view. Responses were quantified and scaled on the basis of the number of terms used. To derive the percentage functions presented in the lower panel of Fig. 1, we averaged Boynton and Gordon's data at each wavelength and divided the mean number of points for each term by the total number of points for all terms at each wavelength.
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18. Infants' looking was unrestrained, and looking time, the dependent variable, was judged in real time by observers ignorant of both the stimulus wavelength and the infant group. The range of interobserver reliabilities was .932 to .969. Only data from the test phase following habituation are included and represent the means of three trials each for stimuli HS, CS, and BS. Significance of differences among these means was handled within an individual comparisons analysis of variance design [B. J. Winer, *Statistical Principles in Experimental Design* (McGraw-Hill, New York, 1971), pp. 384–388] in which specific, theoretically predicted comparisons (BS versus HS and CS) were tested. No stable sex differences were found.
19. Supported by grants from the Grant Foundation, Inc. and from the Carnegie Corporation of New York; and an NIMH postdoctoral fellowship award 1 F22 MH58197-01 to M.H.B. We thank M. Clemens and N. Kasimer for observing, N. Cox, F. Davis, and C. Zimmer-Hart for technical assistance, and L. E. Marks and H. G. Bornstein for reading the manuscript. Correspondence should be addressed to M.H.B.
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11 March 1975; revised 23 July 1975