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Age at Onset of Blindness and the Development of the Semantics of Color Names

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Sixteen college students who had been born totally blind, 16 who had been blinded totally at approximately 15 years of age, and 16 who had normal vision were asked to judge the similarities between color names. These judgments were submitted to the multidimensional scaling program INDSCAL. Like the sighted and the adventitiously blind, the congenitally blind yielded a 2-dimensional space in which the color terms formed a circle with the color names ordered in approximately the spectral sequence, red, orange, gold, yellow, green, turquoise, blue, purple, and violet, around the circumference. Contrary to previous research, the present findings suggest that knowledge of color relations can develop in the absence of first-hand experience with color perception.

Recent research by Shepard and Cooper suggests that color concepts which develop in the absence of first-hand color perception may be imprecise and unstable (Shepard & Cooper, Note 1). In their experiment 6 adults who had been blind from birth and 14 adults with normal vision were asked to judge the similarities between the colors in all 36 pairs drawn from the nine color names blue, gold, green, orange, purple, red, turquoise, violet, and yellow. The judgments made by the congenitally blind differed from those made by the sighted. Submitted to multidimensional scaling analysis, the judgments by the sighted yielded a 2-dimensional space in which each of the nine color names found a unique position around the circumference of a circle. Interestingly, the order of the color names, which was red, orange, gold, yellow, green, turquoise, blue, purple, and violet, conformed to the sequence of colors in the spectrum.[1] A quite different arrangement however emerged from the judgments made by the six blind adults. Virtually no trace of a color circle was to be found in the

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[1] Miller and Johnson-Laird's (1976, pp. 344–345) identification procedure for color terms provides one possible explanation why multidimensional scaling might recover the familiar color wheel from similarity judgments made by the sighted.

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2-dimensional space derived from their judgments; instead the color names fell into two large clusters, one encompassing the warm colors, red, orange, yellow, and gold and the other, the cool colors, green, turquoise, blue, purple, and violet. Moreover, variability among blind subjects was high. These results seemed to suggest that although the congenitally blind acquire some knowledge about colors, their color concepts fail to gain the same precision, stability, and richness as the color concepts of the sighted.

The present experiment, designed to test the developmental implications of these findings, was concerned with the influence of age at onset of blindness on the development of color concepts. The specific question of interest was whether the color concepts maintained by the adventitiously blind, individuals who lose their sight in childhood, adolescence, or later in life, resemble those of the congenitally blind or those of the sighted. To explore this question a procedure similar to that used by Shepard and Cooper was administered to congenitally blind (early blind), adventitiously blind (late blind), and normally sighted college students.

METHOD

Subjects

Subjects were 48 students from colleges and universities in and around New York City. Blind subjects were asked about extent of blindness, age of onset, and cause of blindness. Eight males and eight females who had been diagnosed as totally blind by 6 months of age made up the early-blind group. Eight males and eight females who had become totally blind by approximately 15 years of age (range 6 to 30 years) made up the late-blind group. Causes of blindness are summarized in Table 1. Eight males and eight females made up the sighted group. The mean IQ, measured by the

TABLE 1

CAUSE OF BLINDNESS

Cause	Late blind	Early blind
Glaucoma	5	2
Diabetes	1	0
Dislocation of the lens	1	0
Retinal detachment	1	1
Retinoblastoma	1	1
Retrolental fibroplasia	2	12
Auto accident	3	0
Multiple causes[a]	2	0
Total	16	16

[a] Multiple causes were disease of the optic nerve, uveitus, cataracts, and glaucoma for one subject and retinal detachment and glaucoma for the other.

verbal portion of the Wechsler Adult Intelligence Scale (Wechsler, 1955), was 114 for the early blind, 113 for the late blind, and 115 for the sighted. Mean age was 23 years for the early blind, 26 years for the late blind, and 20 years for the sighted.

Procedure

Each of the 36 pairs drawn from pairing each of the nine color terms blue, gold, green, orange, purple, red, turquoise, violet, and yellow with every other was typed or brailled on a separate 7.62 cm × 12.7 cm card. The deck was presented in one of eight random orders to subjects asked to first skim through and then read the deck thinking meanwhile about the extent of the similarity between the colors in each pair. Two colors were to be considered similar if they blended into each other. To illustrate blending, subjects were told that since white blends through gray into black, white and gray should be considered more similar than white and black. Subjects were then required to rate without feedback each color pair on a 9-point similarity scale where a score of 9 indicated the greatest possible similarity and a score of 1 indicated the least possible similarity. The purpose of the rating task was to allow subjects to practice considering the degree of similarity between colors.

The experimental test consisted of having each subject rank the 36 color pairs in order of similarity. Subjects were asked to select the seven or eight most similar color pairs; to select the seven or eight least similar color pairs; and then to divide the remainder into three categories, the leftovers with the greatest similarity, those with the least similarity, and those intermediate in similarity. Finally by rank-ordering the pairs within each group and combining groups, each subject created a rank order of the 36 color pairs arranged by decreasing similarity from the most similar pair on the top of the deck to the least similar pair on the bottom. When the task was completed, subjects were asked to introspect about how they had arrived at their judgments. The experimenter asked what strategies, if any, subjects had used in ranking the color pairs, with specific interest in whether subjects had thought of the color sequence in the rainbow, or around the color wheel often used to demonstrate how to mix and blend paints, or in one of the memory mnemonics popularly used to aid recall of the order of colors in the spectrum (e.g., the acronym Roy G. Biv). The verbal portion of the Wechsler Adult Intelligence Scale (Wechsler, 1955) was also administered.

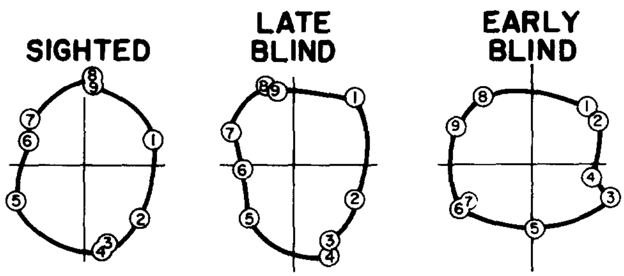
RESULTS

Relations Among Color Names

The experiment yielded 16 rank orders for the early blind, 16 for the late blind, and 16 for the sighted. Each group of 16 rank orders was submitted to the multidimensional scaling program INDSCAL (Carroll & Chang, 1970; Carroll, 1972). Multidimensional scaling is a statistical procedure by which subjects' judgments of similarity can be converted into distances in a 2-dimensional or more complex space. Given an arbitrary space, the judged items, color names, are placed within it so that the distances between them correspond to the judged similarities as much as possible. Thus, if the most similar pair is yellow and orange, yellow and orange should be located closest together in the space, and if green and red are judged the least similar, they should be located furthest apart. Inasmuch as INDSCAL is a metric multidimensional scaling algorithm, the rank orders were converted to numerical distances using Torgerson's procedure (Torgerson, 1958). INDSCAL, incidentally, was selected over the nonmetric scaling algorithm KYST (Kruskal, Young, & Seery, 1973) in order to maximize comparability with the foregoing work of Shepard and Cooper (Note 1) as well as to take advantage of its capability to assess individual differences between subjects.

Using a randomly generated starting configuration 4-, 3-, 2-, and 1-dimensional solutions were found for each group. The fraction of variance accounted for by each solution (estimated by squaring the correlation between the distances obtained from the rank data using Torgerson's method and the fitted distances from the INDSCAL algorithm) was .83, .81, .79, and .55 for the sighted, .79, .76, .72, and .48 for the late blind, and .58, .51, .44, and .27 for the early blind. For all groups the fractions yielded by 4-, 3-, and 2-dimensional solutions seemed of negligible difference while the fractions yielded by the 1-dimensional solutions seemed uniformly low. Inasmuch as the 2-dimensional solutions not only were the easiest to visualize but also fit the input ranks approximately as well as the solutions of higher dimensionality, they were used as the basis of comparison between groups.

As Fig. 1 illustrates, each of the groups yielded a color wheel in



COLOR LEGEND:

1. RED 2. ORANGE 3. GOLD 4. YELLOW 5. GREEN
6. TURQUISE 7. BLUE 8. PURPLE 9. VIOLET

FIG. 1. The 2-dimensional spaces yielded by INDSCAL.

2-dimensional space. The 2-dimensional summaries in Figs. 1, 3, and 4 have been positioned uniformly to facilitate comparison with violet in or near the top-left quadrant and red in or near the top-right quadrant. Inspection of Fig. 1 suggests that all three groups yielded extremely similar 2-dimensional summaries. Notably the early blind differ from the other two groups by inverting the order of gold and yellow and purple and violet. The patterns in Fig. 1 emerged again when the rank orders were submitted by group to INDSCAL a second time with new random starting configurations. Moreover, the pattern yielded by the early blind remained undisturbed when early blind rank orders were submitted to INDSCAL a third time using as a starting configuration estimates of the stimulus coordinates reported by Shepard and Cooper (Note 1).[2]

Consistency within Groups

The extent to which judgments made by individuals concur with the corresponding group solution was assessed using a feature of INDSCAL which determines the relative importance, or weight, of each dimension to every subject and yields a plot, called the *subject space*, in which each subject is located using his or her own weights with respect to the group–solution dimensions. The distance between a subject and the origin of the subject space represents the proportion of variance in the subject's input (converted to distances using Torgerson's procedures) accounted for by the group solution. The greater the distance between the subject and the origin, the larger the fraction of variance accounted for (Wish, Deutsch, & Biener, 1972; Carroll, 1972).

Three subject spaces corresponding to the three group solutions in Fig. 1 have been combined in Fig. 2. The figure shows that the late blind and sighted cluster together more than the early blind. Specifically, all of the sighted, all but one of the late blind and 7 of 16, or 44%, of the early blind concur with their respective group spaces to the extent that more than 50% of the variance in their input has been accounted for. When the criterion is relaxed to 33% of the variance, all of the late blind and 10 of 17, or 63%, of the early blind fall above it.

To illustrate both what the 33% and 50% criteria represent and also to demonstrate the range of variability within groups, the original rank orders from the subject in each group with the largest and the subject with the smallest fraction of variance accounted for were submitted to the nonmetric multidimensional scaling program KYST (Kruskal, Young, &

[2] Inasmuch as INDSCAL assumes metric input, the average rank order for each group was submitted to the nonmetric multidimensional scaling program KYST (Kruskal, Young, & Seery, 1973). The hue circle emerged from the 2-dimensional solutions yielded by each of the three groups. Stress (Formula II) was 0.13 for the early blind, 0.04 for the late blind, and 0.02 for the sighted.

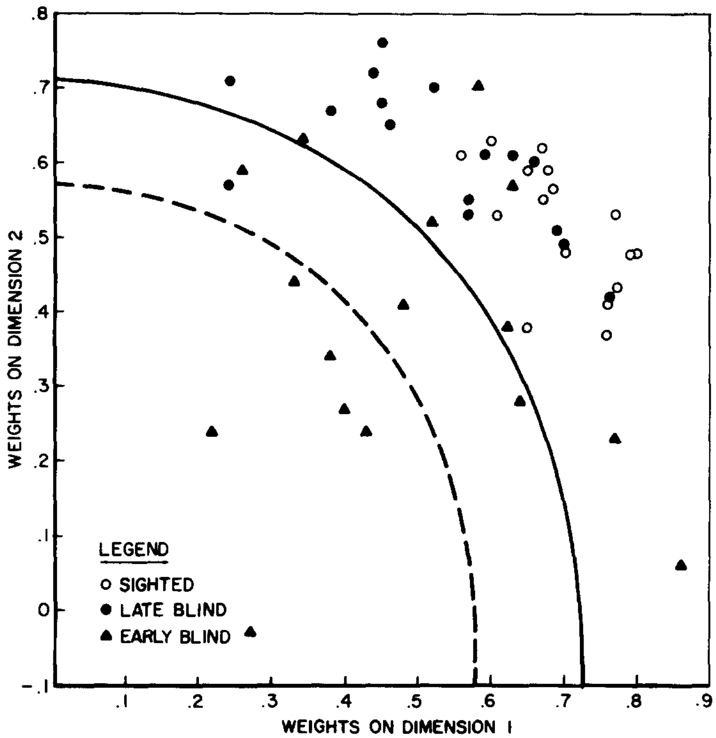


FIG. 2. One subject space combining the subject spaces for the sighted, late blind, and early blind. To the right of the solid contour fall the subjects for whom at least 50% of the variance is accounted and to the right of the dashed contour fall the subjects for whom at least 33% of the variance is accounted by INDSCAL.[3]

Seery, 1972). The resulting 2-dimensional solutions appear in Fig. 3. The fraction of variance accounted for by INDSCAL with 2-dimensions was .87, .66, .79, .38, .83, and .08 for subjects 1, 2, 3, 4, 5, and 6, respectively. Subjects 1, 2, 3, and 5 fall above the 50% criterion in Fig. 2. Subject 4 falls between the 50 and the 33% criteria and subject 6 falls below the 33% criterion. Stress yielded by the 2-dimensional, KYST solutions (Formula II) was 0.08, 0.10, 0.14, 0.17, 0.12, and 0.27 for subjects 1, 2, 3, 4, 5, and 6, respectively.

Figure 3 illustrates that the range of variability is much greater among the early blind than among the late blind and the sighted. Nevertheless, even among the early blind understanding of color relations seems surprisingly good with at least seven early blind subjects above the 50% criterion in Fig. 2. The late blind fall between the early blind and sighted in variability.

[3] Dimensions 1 and 2 are shown in Fig. 1. For the sighted and late blind, dimension 1 is vertical. For the early blind dimension 1 is horizontal.

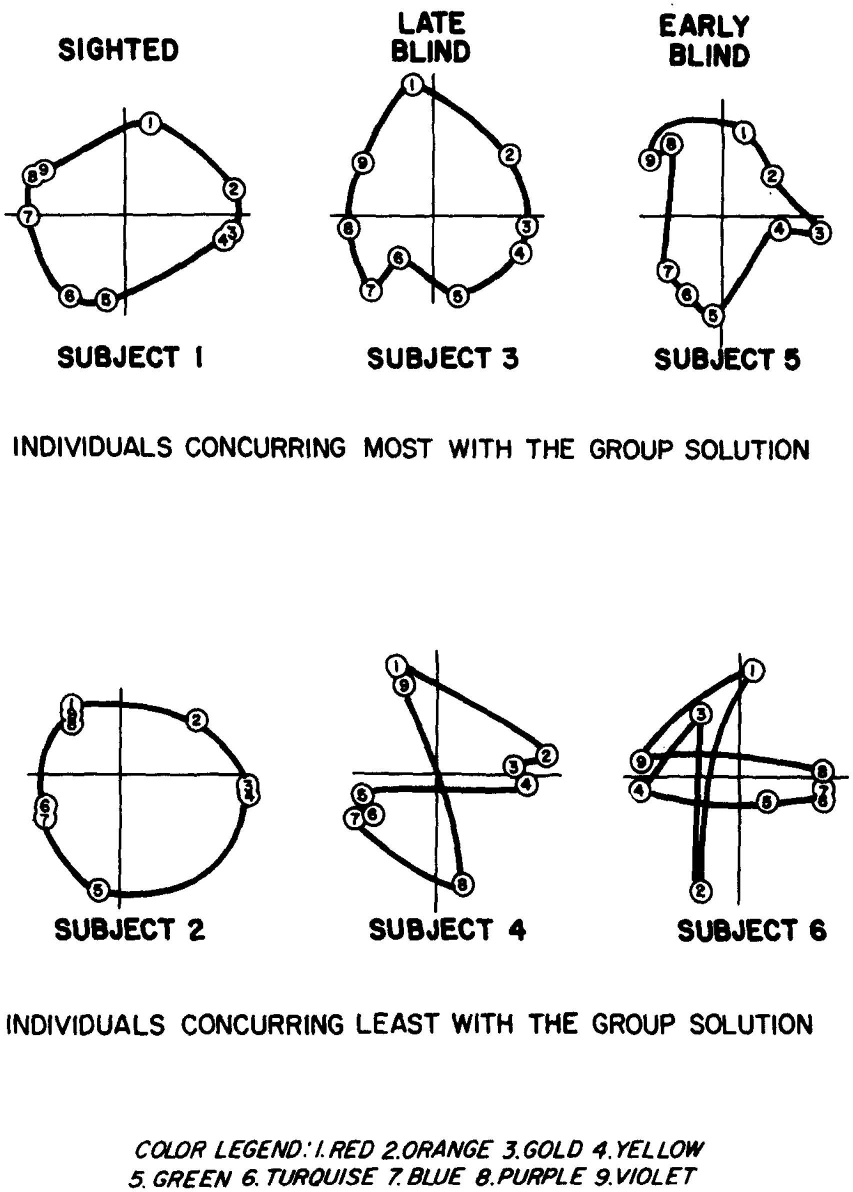


FIG. 3. The range of variability within sighted, late blind, and early blind groups.

Individual Differences and Introspection

An attempt was made to find out whether intelligence, sex, and age-year at onset of blindness might covary with the proportion of variance accounted for by INDSCAL. The Pearson product-moment correlations between intelligence (WAIS Verbal Score) and variance accounted for was

.65 ($P < .005$) for the early blind, .46 ($p < .04$) for the late blind, and .76 ($p < .001$) for the sighted. The Pearson product-moment correlation between age-year at onset of blindness and variance accounted for was .30 ($p < .16$) for the late blind. Fisher Exact Tests performed for early blind, late blind, and sighted separately yielded no evidence of association between sex and ranking above the median variance accounted for.

With respect to response strategies, five early blind, four late blind, and seven sighted subjects reported that they used a spectral model (e.g., the light spectrum, the color wheel, or the rainbow) to make ranking the color pairs easier. However, ten early blind, nine late blind, and three sighted subjects reported that they had neither used nor thought of applying a spectral model. One early blind, three late blind, and six sighted subjects gave uninterpretable reports (e.g., self-contradictory or uncertain) and were excluded from further analysis. Fisher Exact Tests performed for the early blind, late blind, and sighted separately yielded no evidence of association between mentioning a strategy based on knowledge of the spectrum and ranking above the median variance accounted for. Moreover, the internal analysis shown in Fig. 4 revealed no better color wheels in the INDSCAL solutions yielded by the groups that reported using a spectral model than by the groups that reported using no spectral model.[4]

The early blind were asked to describe how they had come to learn about colors and the similarities between them. No instances of formal training were reported, with the exception of the few subjects who mentioned learning about the color spectrum in science classes. The early blind tended to stress two kinds of color experience: (1) chance conversations in which colorful objects and events like rubies and sunsets were discussed, and (2) conversations about how to dress to please the sighted public.

DISCUSSION

In light of previous research suggesting that the early blind know very little about color relations (Shepard & Cooper, Note 1), the outcome of the present investigation was unexpected. Shepard and Cooper tested 14 sighted, 11 color blind, and 6 early blind subjects, three groups that differ in their exposure to color. The early blind learn about color through conversation and reading, that is through language. To language experience, the color blind add experience with a limited range of colors

[4] The average rank order for each of the six groups was submitted to KYST (Kruskal, Young, & Seery, 1973). The hue circle emerged from each 2-dimensional solution. For those who reported using a spectral model stress (Formula II) was 0.165 for the early blind, 0.142 for the late blind, and 0.009 for the sighted. For those who reported using no spectral model, stress (Formula II) was 0.156 for the early blind, 0.085 for the late blind, and 0.086 for the sighted.

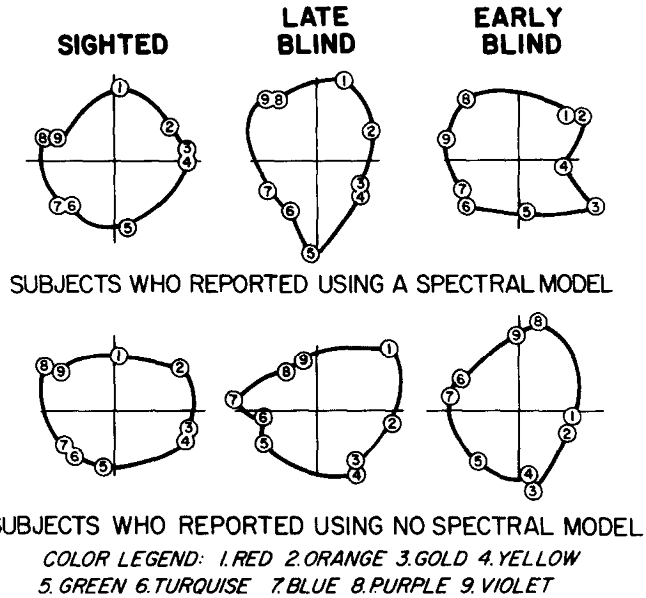


FIG. 4. The sighted, late blind, and early blind partitioned according to introspective reports yielded six 2-dimensional spaces derived by INDSCAL.

and the sighted add experience with the full color range. Shepard and Cooper found that similarity rankings of color names submitted by the sighted and color blind yielded color wheels like the ones presented here. The rankings made by the early blind however yielded two crude clusters which corresponded to the warm and cool colors, but which reflected very little precise understanding of other relationships. These data seemed to indicate that first-hand visual experience of color might be requisite to the development of an adequate conception of color relations. Shepard and Cooper suggested that although color blindness need not be an obstacle, without first-hand experience of at least some colors most of the information about color relations which is implicit in language goes unassimilated.

It was surprising to find that the protocols belonging to the early blind subjects tested in the present experiment revealed knowledge of color relations which was almost as precise as that of the sighted. Responding to experimental procedures similar to those used by Shepard and Cooper, the early blind group in the present study yielded the color wheel as did the sighted and late blind and the sighted and color blind in Shepard and Cooper's experiment. Further analysis demonstrated that the configuration was not an artifact of combining what knowledge the early blind as a group had. In sum, the evidence indicated that lack of visual experience need not preclude an accurate understanding of color relations. Methodological differences may account for the contradiction between Shepard and Cooper's findings and the present results. The ages of subjects at testing which were not reported by Shepard and Cooper may not be comparable between studies and, especially if the early blind learn color names over a relatively protracted period of time, knowledge would be expected to vary as a function of age. Moreover, the number of subjects tested was not comparable. In testing only 6 early blind individuals, compared with the present 16, Shepard and Cooper may not have tapped the range of knowledge seen here. Further research is needed to establish the origin of the disagreement between outcomes.

In what way do color names differ in meaning for the early blind? According to Miller and Johnson-Laird (1976), word meanings serve five main functions: (1) relating the word under consideration to other words in the same semantic domain (intension), (2) providing access to knowledge in long-term memory, (3) indicating syntactic and semantic constraints to be observed when using the word in a sentence, (4) telling the function or purpose of the entity to which the word refers, and (5) indicating what is, and what is not, an entity that can be labeled with that word (extension). The present results suggest that the early blind can and do learn the relations between color names (function 1). Moreover, there seems little reason to suspect a deficit among the early blind in functions 2–4. However, the early blind would be expected to have no way of obtaining access to the knowledge necessary to support function 5, associating color names with the entities to which they refer. It is in not providing denotation sufficient to allow the early blind to point to the entities to which color names refer (assuming, of course, a miraculous recovery of sight) that these meanings are deficient. Among the early blind intensional meaning of color names develops independently of extensional meaning. Could it be that intensional meanings of color names learned through language experience develop at first more or less independently of extensional meaning among sighted children? Sighted children are surprisingly slow to name colors, although color discrimination is possible from infancy. Perhaps in order for extensional relations to be firmly assimilated, the intensional meanings of color names must be firmly grasped (Miller & Johnson-Laird, 1976).

How did the early blind come by their knowledge of color relations? According to self-reports early blind subjects learned about color relations in the course of conversations about colorful objects like rubies and while being instructed in practical activities like dressing. Although few thought formal schooling contributed much to their knowledge of color relations, content analysis of the elementary reading textbooks used by the blind should show that they supply information about color vocabulary. Moreover, school curricula designed for the blind may emphasize color vocabulary just as they stress other visually oriented words like geographic terms (Franks & Nolan, 1970). Dictionary definitions also provide information about color relations. Thus, for example, in *Webster's Third New International Dictionary* yellow is described as "somewhat less red than orange" and purple like violet is described as "any of various colors that in hue fall midway between red and blue." Using such definitions, judging the similarities between colors could become a simple logical exercise. Two colors might be judged highly similar if each is included in the description of the other, whereas they might be judged less similar if they were each included in the definition of a third color but not in the definition of each other. The grammar of the English language also provides information about color relationships. Thus, for example, "bluish" properly modifies green, denoting hues at the blue-green boundary, whereas "bluish" does not properly modify yellow because the colors are separated in the spectrum by green. Two colors might be judged highly similar if they can be used to modify one another using the "ish" construction appropriately and less similar when the "ish" construction is inappropriate. In sum, information sufficient to yield the highly accurate color judgments observed here is available to the early blind.

Little has yet been said about the late blind. They seem to fall between the early blind and the sighted with respect to range of individual understanding (Figs. 2 and 3), suggesting that knowledge of color relations is influenced by either extent of visual experience, recency of visual experience, or both factors.

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