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INTERNAL REPRESENTATIONS,CATEGORIZATION AND CONCEPT OF COLORS IN PURE ALEXIA WITH COLOR NAMING DEFECTS

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It is well recognized that disturbances of color identification are almost consistently found in association with pure alexia. There have been some case reports on pure alexia with particular reference to color naming defects (Stengel 1948, Kinsbourne and Warrington 1964, Critchley 1965, Geshwind and Fusillo 1966, Oxbury J.M., Obury S.M. and Humphery N.K. 1969, Scotti and Spinnler 1970, Mohr,J.P., Leicester,J., Stoddard,L.T. and Sidman.M., 1971, Iwata 1977, Yokoyama K., Yamadori S. and Matsuo T. 1980), but most of these authors have not attempted any experiments other than routine neurological examinations.

One of the most extentive case studies with repect to the color identification problem in pure alexia without agraphia was done by Geshwind and Fusillo (1966). The case they studied failed all the tasks in which he was required to match the seen color with its spoken name. Conversely, he passed all the tests where he could match the color either purely verbally or nonverbally. Based on the postmortem studies of infarction of the left calcarine cortex and of the splenium in this patient, they concluded that the lesion had destroyed the connective fibers of the splenium which carry the corosal fibers of the visual cortex. Thus,the left visual cortex is "cut off from the speech area in the left hemisphere. This visual-verbal disconnection explains both the reading deficit and the inability to name colors or comprehend their names." (Geshwind and Fusillo 1966). If this speculation is tenable, the structure of the internal representaion of colors and long term color memory including the "color concept" should be also intact in pure alexic cases with color identification problems. Recently we have had the opportunity to study two patients with pure alexia by means of conducting experiments specifically designed to investigate the internal representation of colors (color images),color categorization and the concept of colors in pure alexia. This is a preliminary report based on the data obtained from these experiments.

ALEXIC SUBJECTS

The subjects were two pure alexic patients (Case I and Case II). Case I was a 51 year old,right-handed woman. She had right homonomous hemianopia after the evacuation of a subdural hematoma. A CT scan revealed the low density area in the

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junction of left parieto-occipital regions. However, no lesions in the medial portion of the occipital lobe were confirmed. Case II was a 58 year old,right-handed man. He also had right homonomous hemianopia after cerebral infarction in the left hemisphere. The present study was conducted during the priod of nine months to 21 months post onset for Case I and 16 months to 19 months post onset for Case II.

RESULTS OF CLINICAL TESTS OF COLOR IDENTIFICATION

Prior to the experiments on colors, clinical tests with particular reference to colors were given to the patients. Table 1 summarizes the results of these tests (See Appendix as to these tests). Both Case I and Case II showed some errors in the tasks where both verbal and nonverbal processing were required. Case II also failed in the other two tests which could be done in a purely verbal or nonverbal level, suggesting that Case II had some memory problems concerning colors. Case I passed these two tests, indicating that she did not have memory problems concerning colors. Both Case I and Case II passed the Color-Matching and Pseudo Isochromatic Color Test suggesting that they did not have any perceptual problems.

Table 1. Summary of Clinical Tests of Color Identification

Tasks	Case I % correct	Case II % correct
1. Naming of Seen Colors	78% (7/9)	22% (2/9)
2. Matching Seen Colors to Color Name Given Verbally	76% (16/21)	33% (3/9)
3. Verbal Memory for Color of Objects	100% (25/25)	40% (10/25)
4. Matching Seen Colors to Objects Given Verbally	89% (8/9)	22% (2/9)
5. Matching Seen Colors to Picture of Objects	100% (9/9)	22% (2/9)
6. Color-Matching	100% (9/9)	100% (9/9)
7. Pseudo-Isochromatic-Color Test	100%	100%

EXPERIENT I : SIMILARITY JUDGEMENT OF COLORS

SUBJECTS

The two pure alexic patients (Case I and Case II) and one normal subject(age 27) served as subjects for this experiment.

TEST MATERIALS

Test materials used were:(1) Nine colored sheets of paper [red(R), yellowish red(YR), yellow(Y), greenish yellow(GY), green(G), blue(B), purplish blue(PB), purple(P) and reddish purple(RP)] selected from the "Harmonic 166 Colored Cards" which were developed by the Japan Color Research Institute. (2) Nine line drawings of objects (apple, persimmon, banana, lawn, spinach, sea, eggplant and sweet potatoe) whose intrinsic colors matched the nine colored sheets of paper.

PROCEDURES

Experiment I-A:Perceptual Color Condition (PC Condition)

Three colored sheets of paper randomly selected from the nine colors (total of 84 triads) were presented to the subjects in triadic fashion as shown in Figure 1. In the example shown in Figure 1, the three pairs (red vs. yellowish red, red vs. green and yellowish red vs. green) are available to compare and they were asked to choose the two colors which they judged to be more similar than the other two pairs. The two colors chosen by the subjects at each triadic comparison were recorded.

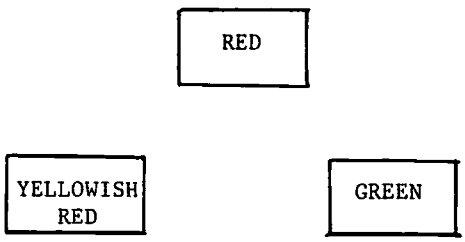

Figure 1. An Example of Triadic Comparison of PC Condition

Experiment I-B:Color Memory Condition (CM Condition)

Three names of colors randomly selected out of nine color names (total of 84 trials) were given verbally to the subjects. They were required to recall the image of these three colors and choose the two color images which they judged to be the most similar. The two color images chosen by the subjects were recorded.

Experiment I-C:Line Drawing Condition (LD Condition)

Three line drawings randomly selected out of nine drawings (total of 84 trials) were presented to the subjects and they were required to recall the intrinsic colors of these objects in order to choose the two intrinsic colors which they judged to be the most similar. An example of a triadic comparison in the LD condition is shown in Figure 2. The two objects chosen at each triadic comparison were recorded.

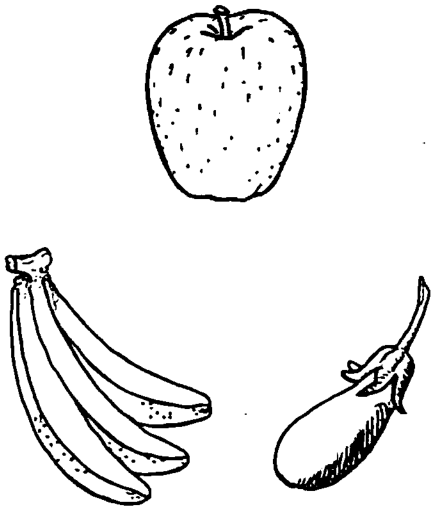

Figure 2. An Example of Triadic Comparison of LD Condition

RESULTS AND DISCUSSION

The subjects' responses to the three color similarity judgment tasks were analyzed in terms of the frequencies with which the subjects chose a particular color pair as more similar than other pairs. The frequencies were converted into correlation matrices and analyzed using multidimensional scaling (MDS). The two or three dimensional solutions of colors were obtained using MDS for each experimental task separately.

As figure 3 shows, the results of the normal subject's performance on three tasks were resolved in two dimensions. Except for the relations between blue(B) and purplish blue(PB) under the CM condition and reddish purple(RP) and purple(P) under the LD condition, the solutions corresponded perfectly with Munsell's Color Circle. Furthermore, the same colors under the three different conditions were plotted in basically the same areas in two dimensional space.

On the other hand, as Figures 4 and 5 indicate,the results of Cases I and II were best expressed in three dimensions in which greenish yellow(GY) and purplish blue(PB) were not included because these mixed colors were judged to be unstable colors with other colors even in normal subjects. As shown in Figure 4, the three dimensional solutions of the PC condition (top) are identical to Munsell's Color Circle. The same correspondence was also confirmed in the solutions of the MC condition (middle) and the LD condition (bottom).

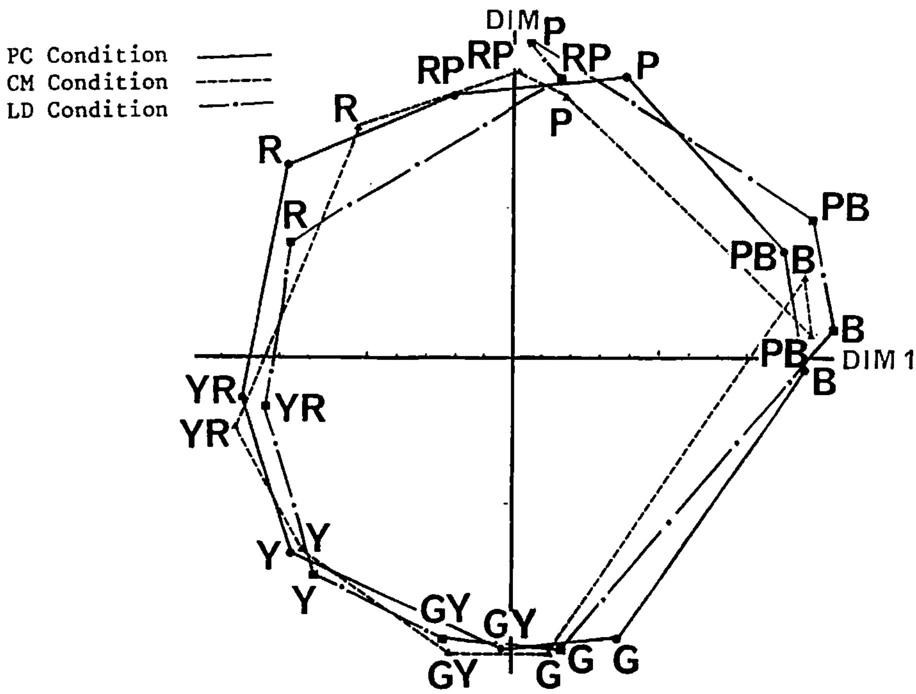

Figure 3. Two Dimensional Solutions of the Colors under the Three Conditions (Normal Subject,K.H.)

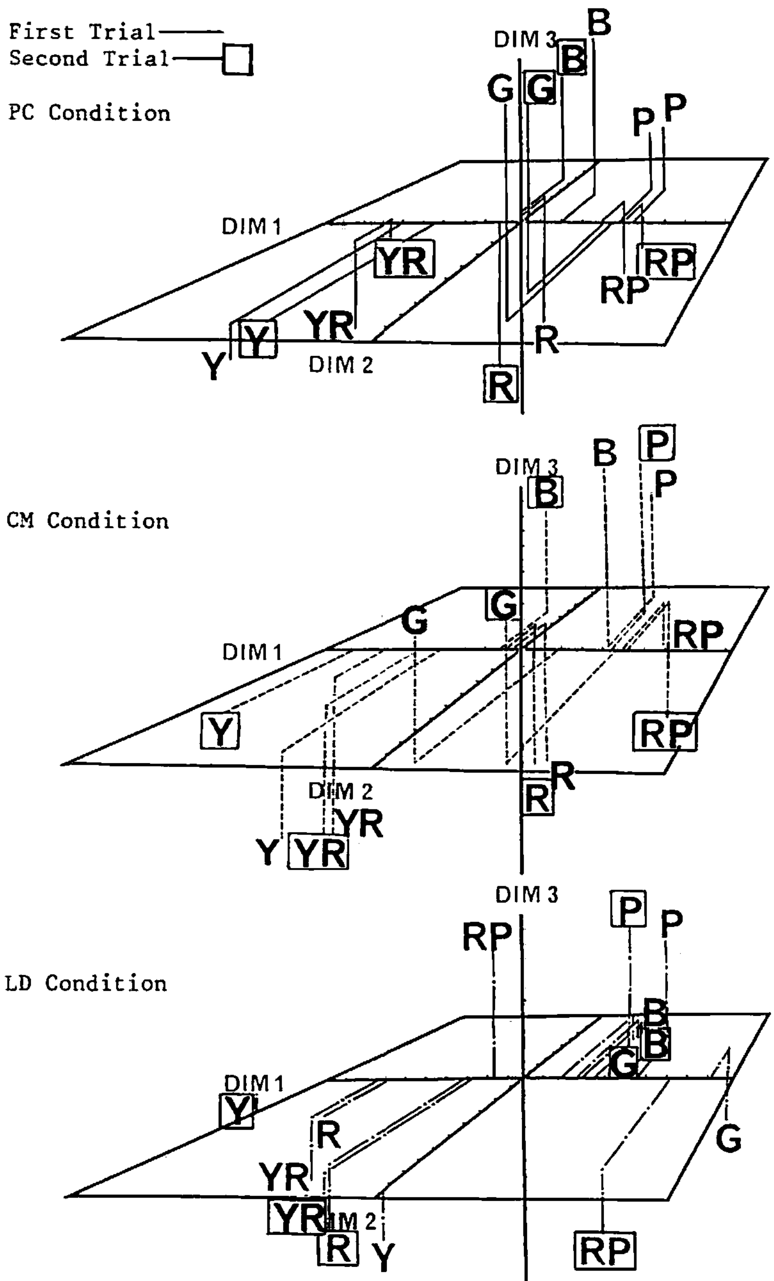

Figure 4. Three Dimensional Solutions of the Colors under the Three Conditions (Pure Alexic Case I)

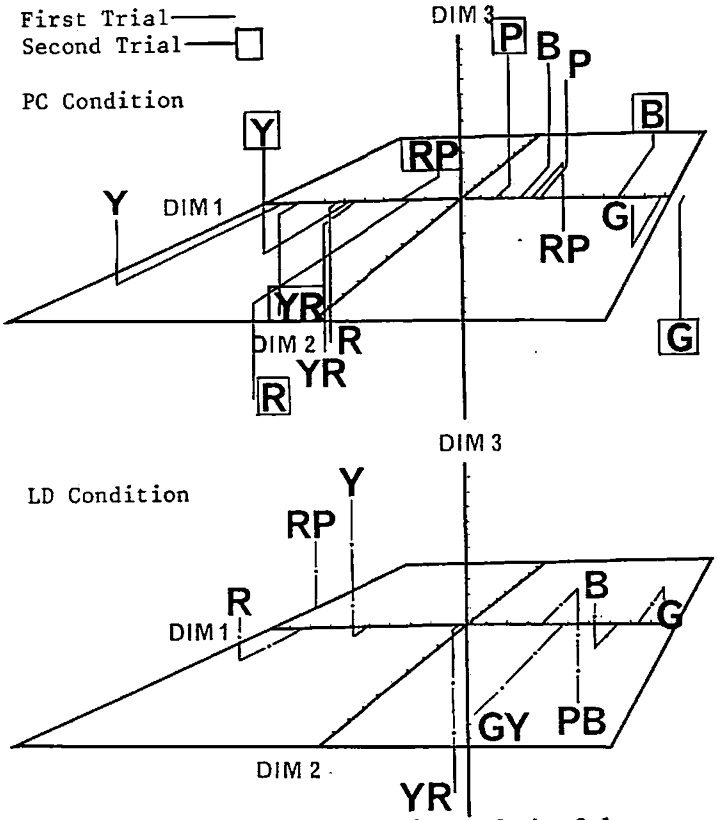

Figure 5. Three Dimensional Solutions of the Colors under Two Conditions (Pure Alexic Case II)

Since Case II mentioned that he could not recall any color images besides blue, red and yellow, the task under the MC condition was not performed. Also under the LD condition, a line drawing of "eggplant" was ommitted from the task because he could not identify the intrinsic color of the object prior to this task. As Figure 5 shows, three dimensional solutions of both the PC (top) and LD (bottom) conditions neither match Munsell's Color Circle nor do these two solutions correspond to each other. However, when colors which spatially approximate each other were grouped into clusters, the members of each cluster belonged to basically the same color group, i.e. bluish color and reddish color. This suggests that he is capable of grouping these colors based on the general color groups.

It has been reported that the performance of similarity judgment of colors in normal subjects can be expressed two dimensionally since colors are usually perceived in terms of hue alone (Masui,1977). On the other hand, as figures 4 and 5 indicate, pure alexic subjects might have utilized "lightness" as a cue in the triadic comparison tasks. Thus, dimension 3 in Figures 4 and 5 can be interpreted as the dimension of "lightness".

Apart from such differences, some similarities were observed between the normal subject and Case I. The dimensional solutions of the normal subject and Case I were quite similar in the sense that they approximated Munsell's Color Circle although Case I seems to have utilized "lightness" as a cue in similarity judgment. Furthermore, there was a correspondence between the solutions of the PC condition and the rest of the conditions. This correspondence suggests that the criteria they used in similarity judgments in the PC condition were functionally similar to those used in other two conditions. This indicates that the relations among the representations of directly perceived colors (PC condition) and the relations among the internal representations of colors (MC condtion and DL condition) remained intact in Case I. Moreover, it is quite possible to assume that functional correspondence exists among these three color representations. From these observations, it is clear that Case I has normal representations of directly perceived colors and the internal representations of colors.

Conversely, the MDS solutions of Case II did not match Munsell's Color Circle and there was no correspondence between the representations of directly perceived colors and internal presentations of colors. Rather, Case II clustered the colors in terms of cool and warm colors. This suggests a decrease in the operational and functional ability to use the internal representations of colors and inaccuracy in similarity judgment of colors in this particular subject.

EXPERIMENT II: CATEGORICAL JUDGMENT OF COLORS

SUBJECTS

Case I and Case II and four normal controls served as subjects for this experiment.

TEST MATERIALS

Three sets of 20 colored sheets of paper were selected from the "Hue Circle 100" developed by the Japan Color Research Institute. The five physical parameters have been calculated for each color. These parameters are the spectral reflection factor, CIE(Commision Internationale de L'Eclairage) 1931 chromaticity coordinate, Munsell Hue, Munsell Value and saturation. These colored sheets of paper are made in such a fashion that any two colors which are physically adjacent to each other are determined on the basis of just noticeable difference (JND). Each color has an identification number to refer to its physical parameters.

The first set of 20 colored sheets of paper (Set I) consisted of the color range from red to yellow through yellowish red. The second set (Set II) covered the color range from yellow to green through greenish yellow. The third set (Set III) covered the color range from blue to purple through purplish blue.

PROCEDURE

The two most different colors in each set of 20 colors (red and yellow in Set I, yellow and green in Set II and blue and purple in Set III) were selected as constant stimuli. The two constant stimuli in each set were placed in front of the subjects ,one set at a time, and the remaining the 18 colored sheet of paper was also placed, one by one, in the middle of the two constant stimuli. The order of presentation of 18 color stimuli were randomized. Then the subjects were asked to judge to which constant stimulus color a given color stimulus belonged. Thus the subjects were required to perform a two-alternative-forced choice. There was no time limit for each trial. Each set of 20 colors was tested, one at a time, and the task was repeated 10 times (3 sets x 18 colors x 10 times =540 trials). At the end of each trial, which one of the two constant stimuli each color was judged to belong to was recorded.

ANALYSIS OF DATA

The probability that a given color stimulus is judged to belong to one of the two constant stimulus colors was calculated and a probability function (approximate identification curve) was estimated by means of the least square method. Relavant parameters, μ :categorical boundary, σ :accuracy of categorical judgment, were also obtained.

RESULTS AND DISCUSSION

Table 2 shows these values of all subjects and Figures 6,7 and 8 show functions of categorical judgment by normal subjects, Case I and Case II, respectively.

If the subjects' judgment that a given color belongs to one or the other of the two constant stimulus colors is completely accurate, the probability of the judgment will drastically change from zero to one at the categorical boundary of the two colors and the value of σ will be small. The observed probability function and σ in normal subjects demonstrated rather sharp and accurate categorical judgments for each set of colors. This result indicates that normal subjects are keen to the gradual alternation of the physical parameters of colors and have established a sharp psychophysical criterion on which they based their categorical judgments. However, there was inter subject variability in the boundaries within one color range, as well as intra judgmental variablity of boundaries across the three different color ranges, suggesting that the boundaries of each color are relative. Therefore, the value of boundary (μ) will not be discussed here.

The results of pure alexic Case I basically fell within the normal range of performance but the results of Case II indicated relatively inaccurate judgment in Set II. As figure 8 shows, the slope of the identification curve of Case II in Set I is gentle and σ is large, indicating that Case II had some difficulty classifying colors between yellow and green,i.e.,a group of colors falling into greenish yellow.

These findings suggest that the ability of Case I to classify a given color as closer to one or the other constant stimuli remained intact. This further indicates that Case I retained the ability to judge the physical proportion of colors where two different colors are mixed and that he could decide which color category a given color should be classified as refering to the concept of color. Accordingly, the concept of color in Case I is also intact.

The same conclusion can be drawn for Case II except for his performance on the color range from yellow to green. It is possible to assume two different causes of the results shown by Case II. One is that he could not judge the relative proportion of yellow and green or misjudged the proportion, thus he failed to classify a given color into either of the two constant stimuli. However, this interpretation is not probable, because he does not have any perceptual problems. The alternative interpretation which is more plausible is that he did not have a clear concept of colors in particular color ranges, yellow and green, in the first place although he could perceive the colors perfectly,resulting in a failure in categorical judgment of these colors.

Table 2. Values of μ and σ for the Pure Alexic Cases and the Normal Subjects

Pure Alexic Subjects	Age	Sex	Constant Stimuli	μ	σ
Case I	56	F	GY,Y	7.80	1.25
			YR,R	9.90	1.23
			PB,P	13.73	1.09
Case II	57	M	GY,Y	11.90	2.27
			YR,R	12.48	0.49
			PB,B	15.26	0.88
Normal Subjects					
H.O	32	M	GY,Y	9.09	1.21
			YR.R	10.09	1.85
			PB,B	11.81	1.56
H.K	32	M	GY.Y	6.92	0.14
			YR.R	8.92	1.02
			PB.B	15.22	0.26
M.I	43	M	GY.Y	6.13	0.84
			YR.R	12.69	1.26
			PB.B	14.42	0.46
K.H	28	M	GY.Y	10.69	1.40
			YR.R	6.32	0.93
			PB.B	13.66	1.08

GY: Greenish Yellow
Y: Yellow
YR: Yellowish Red
R: Red
PB: Purplish Blue
B: Blue

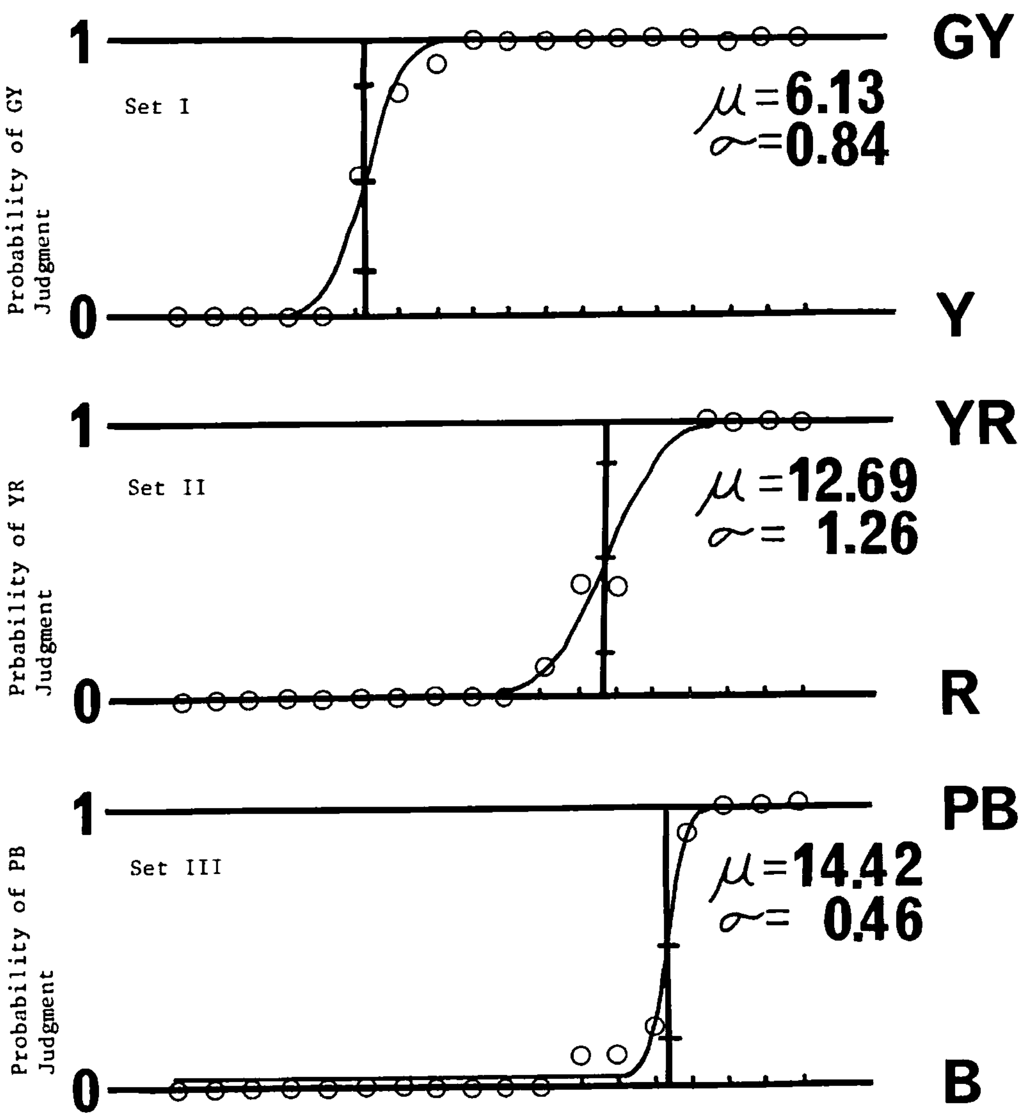

Figure 6. Boundary μ and σ of the Categorical Judgment of the Three Different Color Ranges (Normal Subject, M.I.)

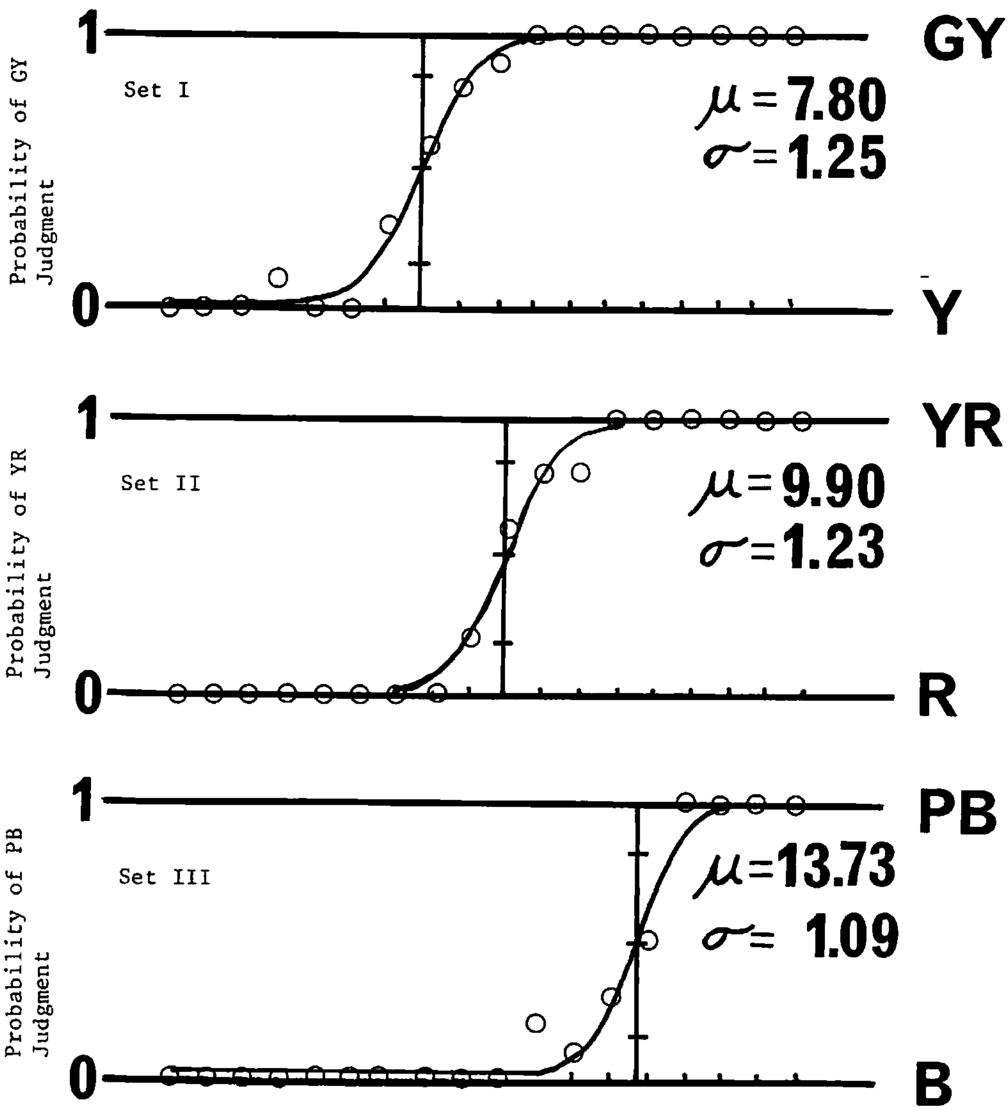

Figure 7. Boundary μ and σ of the Categorical Judgment of the Three Different Color Ranges (Pure Alexic Case I).

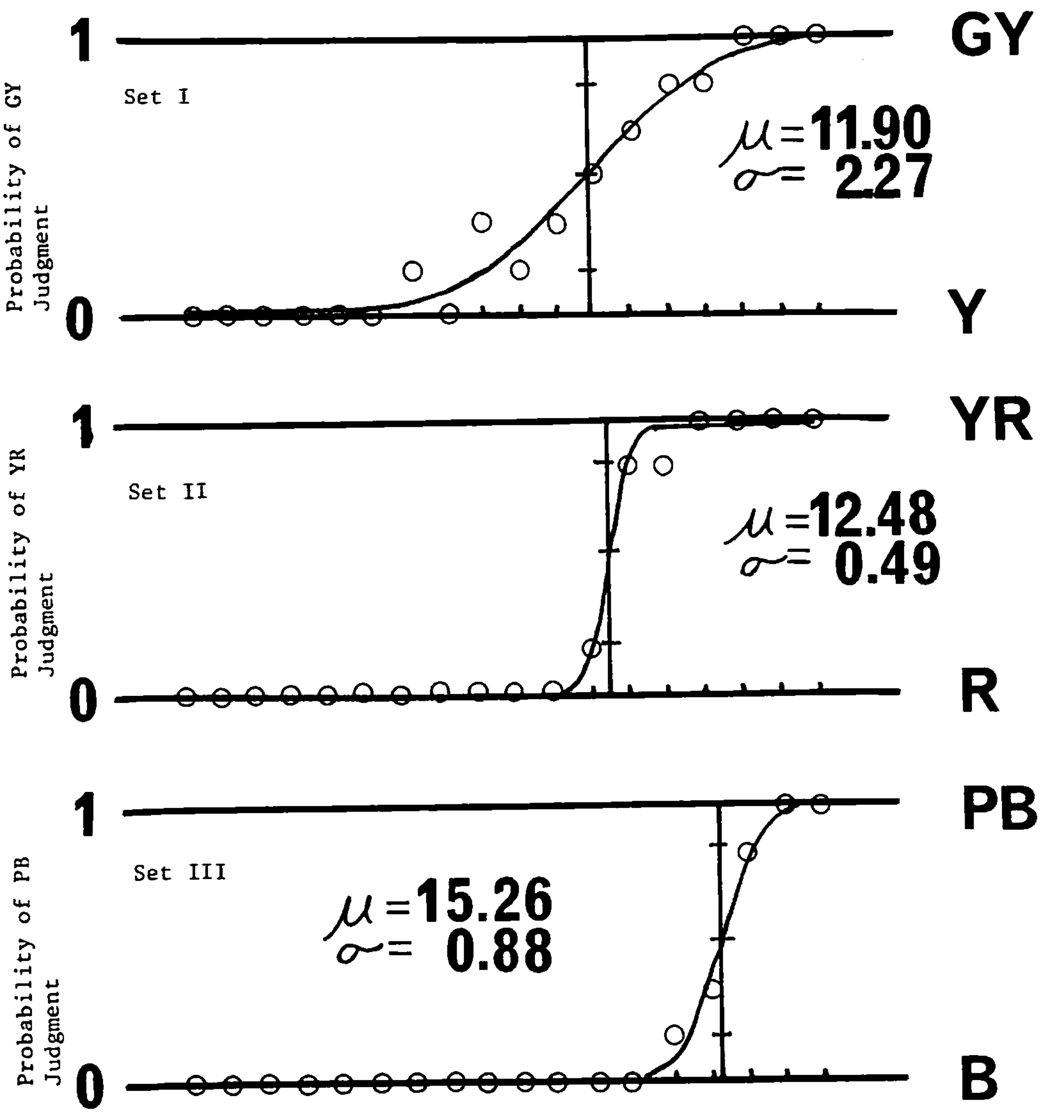

Figure 8. Boundary μ and σ of the Categorical Judgment of the Three Different Color Ranges (Pure Alexic Case II).

EXPERIMENT III: CLASSIFICATION OF COLORS

SUBJECTS

Case I and Case II and three normal subjects were tested in this experiment.

TEST MATERIALS

One hundred colored sheets of paper (Hue Circle 100, part of which was used for Experiment II) were used. "Hue Circle 100" consisted of ten colors (red, yellowish red, yellow, greenish yellow, green, bluish green, blue, purplish blue, purple and reddish purple) each of which is divided into ten gradations on the basis of JND. Each color has an identification number to refer to the five physical parameters.

PROCEDURES

The subjects were given the test materials and asked to do the following tasks in several steps.

STEP 1

The subjects were required to divide these 100 colors into as many color groups as possible based on their perceptual similarity. It was legitimate to form a color group consisting of a single colored sheet of paper. When this task was finished, every single color included in each group was recorded, e.g. Group 1 contains red 1, 2, reddish purple 10. Group 2 contains greenish yellow 9, 10 and green 1. These were considered color groups at the first step.

STEP 2

The subjects were given all these groups of colors formed in Step 1, and asked to put these color groups together based on perceptual similarity. Thus, in Step 2, the number of groups of colors decreased compared with Step 1 and the number of colored sheets of paper within each group increased. When this task was done, each color included in a given group was recorded in the same manner as used in Step 1.

From Step 3 on, the same procedures were repeated until the subjects decided that they could not form any larger groups. At the end of each step, the colors added to a group formed in the previous step were recorded.

The task of color classification requires the subjects to perform at least two different kinds of tasks. At Step 1, 100 colors were divided into as many color groups as possible. In this task, subjects selected the most similar, physically close together colors. This can be done perfectly without refering to the color concept. However, Step 2 on requires the subjects to refer to the "superordinate concept of color" to form larger groups. Thus the first step of this task is considered to be a "color matching" or "data driven" task while the tasks from Step 2 on can be considered "color concept oriented" or a "conceptually driven" task.

ANALYSIS OF DATA

The colors recorded at the end of each step were converted into similarity matrices and all the colors collected together as one group were given arbitral identification numbers, e.g. if red 1, 2, 3 and reddish 8, 9 are grouped together, all these five colors were given the number 1. Then these arbitral numbers given to each group at each step of the procedure were used to calculate correlation matrices for cluster analysis of colors. In actual analysis, 70 colors (color 4,5 and 6 from each color were ommitted) out of 100 were used to minimize the computer processing time.

Cluster analysis produced similarity indices at each step of analysis and the dendrograms at the end. The similarity index varies from one to zero where one refers to perfect correlation and zero refers to no correlation. Thus the similarity index indicates the degree of similarity among the groups of colors. The dendrogram shows the classifications of all 70 colors, dividing 70 into four groups. Approximately the last ten colors of each dendrogram overlap with the first ten colors of the following dendrogram. This method was employed to connect the last ten colors (reddish purple) with the first ten colors (red) in a circular fashion.

RESULTS AND DISCUSSION

Figures 9 ,10 and 11 show the dendrograms and similarity indices for a normal subject (H.O.) and Cases I and II, respectively. The dendrograms and similarity indices provide information concerning each subject's conceptual structure of colors. The horizontal lines in the dendrogram correspond with the similarity index showing at what stage of the color grouping given colors were perceived as one group. Thus, the lower the horizontal lines are located, the earlier the stage of color grouping occurred. Accordingly, the similarity indices become smaller as the stage of the color grouping is delayed. Also the number of horizontal lines obtained indicates easiness of the color classification processes.

The vertical lines in the dendrogram indicate the number of color groups formed through the number of color groupings. The colors between two vertical lines belong to the same color group.

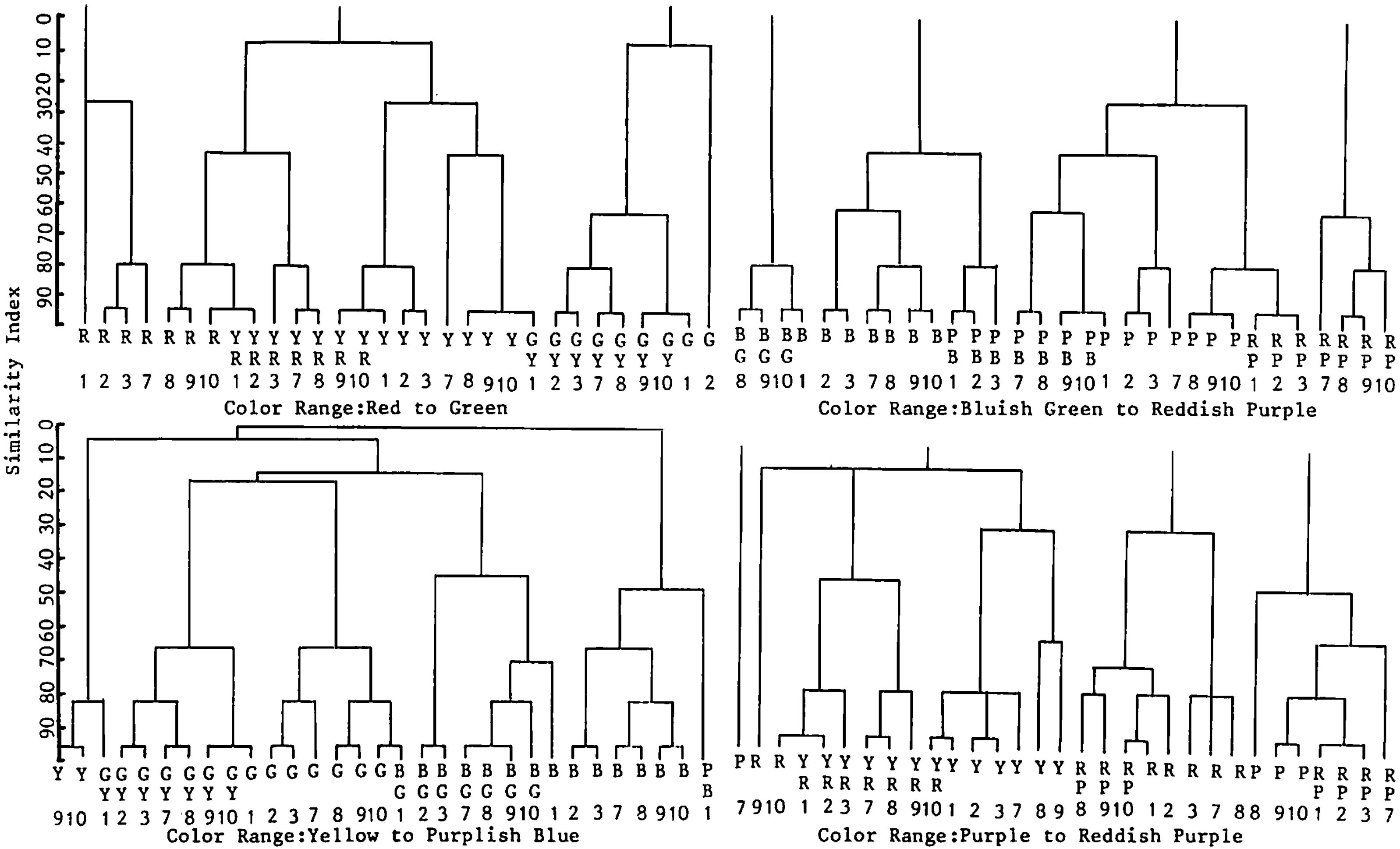

Figure 9. Dendrograms of the Normal Subject (H.O.)

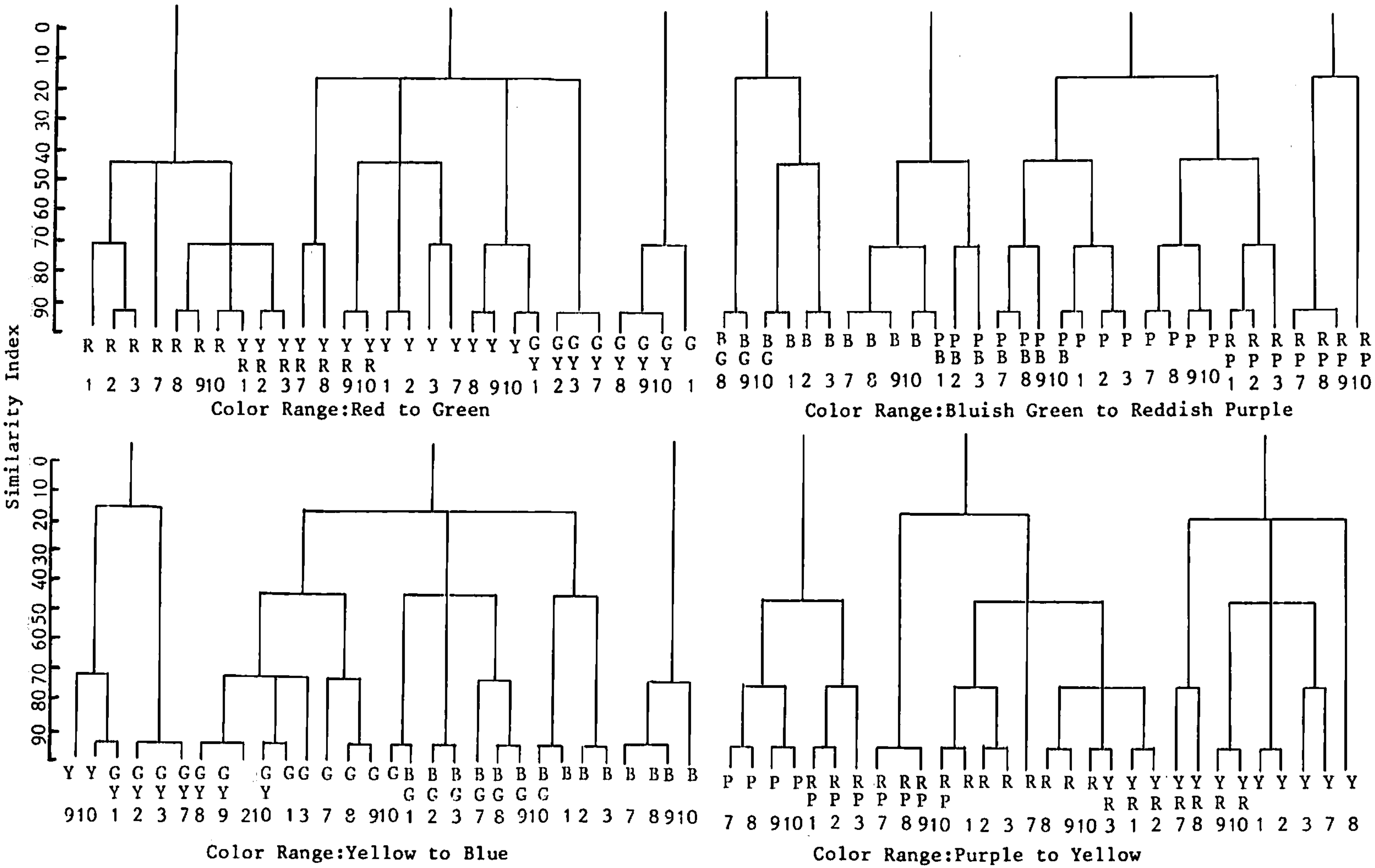

Figure 10. Dendrograms of the Pure Alexic Case I

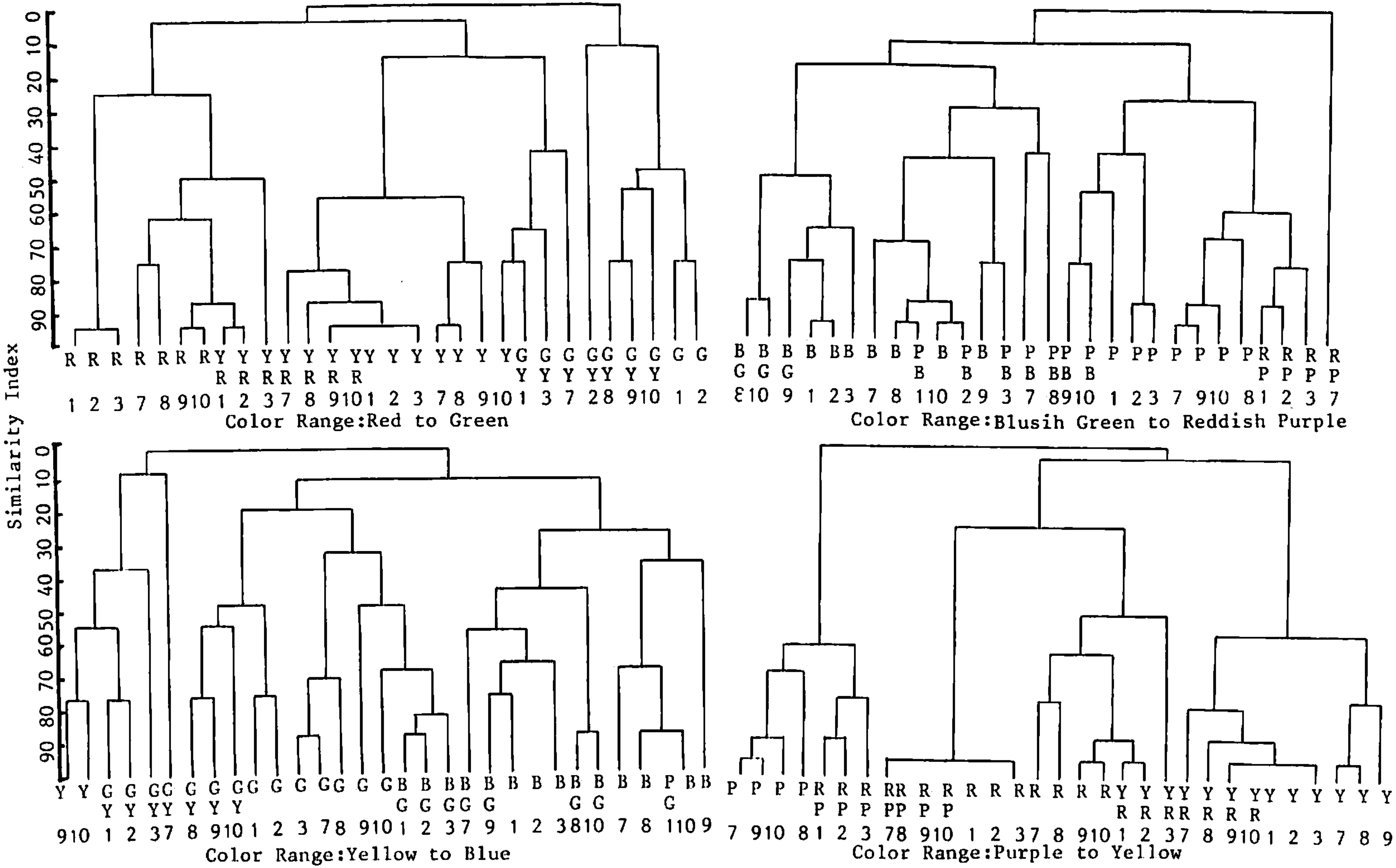

Figure 11. Dendrograms of the Pure Alexic Case II

For example, the lower left of Figure 9 shows that BG 7,8 and 9 were perceived as one color group at the earliest stage of classification and BG 10 was added to the first group at the second stage. At this stage, BG 7 through BG 10 are considered as one color group. Then at the third stage, B 1 was added to the group formed at the second stage.

One of the common features observed among the dendrograms of normal subjects is that only a few vertical and horizontal lines are seen (Figure 9). This suggests that it is not difficult for normal subjects to collect perceptually similar colors together and continue to form larger group of colors based on the color concept.

As Figure 10 indicates, the dendrogram of Case I is practically identical to those of normal subjects indicating that color concept is normal in Case I. Only a few vertical and horizontal lines are seen in the figure indicating that only a few steps were needed to conceptualize all the colors.

In contrast, the results of Case II as shown in Figure 11 are apparently different from those of the rest of the subjects. It should be mentioned here that he had tremendous difficulties doing the task, especially the tasks from Step 2 on. At Step 1, he grouped basically similar colors together. He also put two to three groups together at Step 2, but he could not form any larger groups from that point on. Thus, his performance always terminated at Step 2. In order to obtain reliable data, he was requrired to repeat the same task five times.

Generally speaking, the number of vertical and horizontal lines seen in the dendrograms of Case II are much greater than in any other dendrograms, indicating that it was quite difficult for him to conceptualize colors supporting his appeal that he could not form any larger groups from Step 2 on.

Figure 11 also indicates that his performance was not consistent across different color ranges. Judging from the structure of the dendrograms, it seems that the color ranges of RP 7 to Y 3 through R, YR and Y (upper left and lower right) are very well conceptualized. Color ranges of BG to PB through B and a part of P (upper right) seem to be considerably well conceptualized although a larger number of vertical lines are seen. The largest number of vertical lines with lower values of similarity indices are seen in the color ranges of GY to a part of BG through G (lower left and lower right) indicating that these colors were not well classified or conceptualized.

Based on these findings, it is quite reasonable to assume that Case II certainly has normal color concepts for almost all colors used here, with the exception of GY to a part of BG through G.

GENERAL DISCUSSION

The results of three experiments for Case I and Case II are summarized in Table 3. As Case II showed some color memory problems in clinical tests, the data obtained in Experiment I-C (LD Condition) are not reliable. Thus, an interpretation of his results from Experiment I-C will not be attempted.

All the results of Case I were identical to those of the normal subjects except that the solutions to the similarity judgment of colors were best plotted in three dimensions instead of in two dimensions. This dimensional difference is not critical here, the most important factor being whether or not the solutions matched Munsell's Color Circle. Not only the very complicated psychophysical relations among colors but the concept of colors are remained in the normal way in Case I: therefore, the pathological mechanism underling the color naming defect of Case I may be explained in terms of visual-speech disconnection as described by Geshwind and Fusillow (1966).

Table 3. The Results of Experiments I, II and III (Pure Alexic Case I and II)

	Case I	Case II
Experiment I Similarity Judgment of Colors	Three dimensioal solutions correspond with Munsell's Colo Circle.	Three dimensional solutions do not correspond with Munsell's Color Circle.
Experiment II Categorical Judgment of Colors	Categorical boundary and accuracy of judgment are within normal range.	Accuracy of categorical judgment for particular color range (yellow to green through greenish yellow) is disturbed.
Experiment III Classification of of Colors	The concept of color remains intact.	The concept of color for particular color range (yellow to bluish green through green) is disturbed.

The results of Case II were drastically different not only from the normal subjects but also from Case I, suggesting that the pathological mechanism underlying his color naming defects may be very different from that of Case I. The results of the test of the similarity judgment of colors (Experiment I) showed that the three dimensional solutions of perceived colors did not correspond to Munsell's Color Circle. This suggests that the psychophysical criteria on which he based his similarity judgment were not stable. In other words, in Case II psychophysical relations among the colors are disturbed to a certain extent even though he does not have any perceptual problems.

This interpretation can be supported by the results obtained in the categorical judgment of colors and classification of colors. In the task of the categorical judgment of colors, Case II demonstrated difficulty in categorically judging colors which fell between yellow and green. As the identification curve and the value of σ of these colors shows, colors between yellow and green were not sharply classified by Case II. This task can be very difficult if one does not have a clear concept of colors or the conceptual relations between the constant stimuli and the stimulus color since once a stimulus color is perceived, the next task is to decide to which constant color stimulus the color stimulus should belong. Furthermore, the structure of the dendrogram indicated that Case II was unable to form larger groups of colors ranging from yellow to green, indicating that he has disturbances in color concepts for particular color ranges ,i.e. yellow to green.

Taken together, these findings suggest that there are, at least, two different kinds of color naming defects in pure alexia. The first type does not have any problems in long term color memory, and thus can be explained by visual-speech disconnection where one simply cannot match the name of colors to seen colors. In the second type of pure alexia, on the other hand, long term memory including the concept of color is compromised resulting in higher neurological disturbances of processing colors called "color agnosia". Only the procedures adopted in our study can possibly reveal such disturbances.

APPENDIX

CLINICAL TESTS OF COLOR IDENTIFICATION

The tests used here are as follows:

Naming of Seen Colors

The patients were required to name the color of each sheet of paper presented to them.

Matching Seen Colors to Color Names Given Verbally

A group of nine colored sheets of paper were presented to the patients and they were asked to select a specific color,e.g. "Show me the blue sheet of paper".

Verbal Memory for Colors of Objects

The patients were asked to say the usual color of 25 ordinary objects specified by the examiner, e.g. apples, bananas, sea etc.

Matching Seen Colors to Objects Verbally Given

A group of colored sheets of paper were presented to the patients and they were asked to select the one colored sheet of paper which matched the color of the object given verbally by the examiner.

Matching Seen Colors to Picture of Objects

A group of line drawings of objects and colored sheets of paper were presented to the patients and they were required to match the line drawings and their intrinsic colors.

Color-Matching

A set of nine colored sheets of paper were placed on the desk and a colored sheet of paper were given to the patients one by one so as to be matched to one of these on the desk.

Pseudo-Isochromatic Color Test

The patients were given the Ishihara Pseudo Isochromatic test of color vision.

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