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COLOR DISCRIMINATION UNDER THE CONDITION IN WHICH NONE OF THE ATTRIBUTES ARE EQUALIZED

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ABSTRACT:

The ability to place a color in a color system is necessary to plan a color scheme. Understanding of the color theory and ability to discriminate colors are required to do it. The purpose of this research is to provide a basic material for color education on discrimination of colors under the condition in which three attributes of colors are varied. The experiment process is as follows: A chromatic color chip was shown to a subject. The subject was expected to specify its brightness by the number on the gray scale after comparing it with the scale shown at the same time as the chip. The result indicated difficulty of the discrimination varies according to the chroma, and correct answer rates for hue were observed depending on the particular subject.

Key words: color discrimination, color education, perception

1. INTRODUCTION

The planning of colors and exchange of information involved in design work requires an understanding of the target colors in terms of a color system. At that time, together with an understanding of "color logic" in terms of where each color is positioned within the color system, it is also necessary to have the ability to "discriminate" colors by being able to distinguish between their brightness, vividness and tint. At present, however, there are hardly any courses targeted at color discrimination at institutions of higher learning (such as technical schools, junior colleges and universities) or programs accompanying certification systems that provide color education on the premise of practical work.

The discrimination of color can be divided into two forms on the basis of the properties thereof. The first is discrimination under constant conditions other than the condition to be compared, namely conditions in which two of the three attributes are constant. For example, although the 100-hue test distributed by the Japan Color Research Institute requires discrimination of hue, the other two attributes of value and chroma are constant. Although discrimination is comparatively easy since changes are perceived as quantities as a result of the attribute other than the attribute to be compared being constant, the degree of difficulty increases as the color difference being compared becomes less. This type of discriminative ability is related to physiological function.

The other form of color discrimination involves comparative discrimination of a specific attribute under conditions in which none of the three attributes are constant. This ability is required for practical color planning and color coordination planning. During color planning, the tasks to be performed are presumed to involve matching only the value of colors for which hue and chroma are not constant. For example, in order to match multiple colors on the basis of tone, it is necessary to discriminate between value and chroma and then position them on their respective axes. In addition, the uniformity of value, chroma and hue must be distinguished to produce gradation. The ability to compare and discriminate a specific attribute under conditions in which these three attributes are not constant was contained in previous "Color Certification" test and is known to be required for practical work.

The purpose of this study is to provide basic reference materials for this type of discrimination. The ultimate objective is to establish standards and teaching methods relating to the ability to discriminate colors in color education premised on practical application. The ability to discriminate colors involves expressional skills, and is generally believed to be acquired empirically during the course of practical work. Although there are ways for acquiring this ability through training on the basis of these empirical rules, methodology and reference materials relating to color discrimination cannot be said to be adequate.

A quantitative understanding of the tendency to have difficulty in discriminating each color and the ability to discriminate along with clarification of the manner in which abilities involving perception in the form of color discrimination are related to knowledge and understanding of theory can be expected to contribute color education as related to the setting of levels to be discriminated by professionals, the establishment of teaching methods and so forth.

This report provides a description of the conducting of a research survey relating to color education and discrimination at institutions of higher learning, and the conducting of a preliminary experiment towards the establishment of an experimental method for quantitatively understanding color discrimination. As a result, basic reference materials were obtained regarding the experimental method based on an interview survey, observation of eye movement using an eye mark recorder and an analysis of the experiment results.

2. NEED FOR DISCRIMINATION TARGETED BY THIS STUDY

The discrimination targeted by this study is discrimination under conditions in which none of the three attributes are constant. This discrimination ability is required by professionals engaged in color planning and other practical work. In the case of interior color planning, it is necessary to coordinate such interior components such as walls, floors and curtains. At that time, this planning is premised on such tasks as changing the hue and integrating luminosity, or matching the hue and changing the luminosity and saturation. Comparisons are required to be made of only specific attributes for various colors.

An example of this previously appeared in a question given in The "Color Test" .The "Color Test" is a skill test certified and sanctioned by the Japanese Ministry of Education, Culture, Sports, Science and Technology. This test is designed to serve as a social scale for assessing ability to practically utilize color on the basis of theory. This test is taken by nearly 100,000 persons annually from related fields such as interior, apparel, distribution and various manufacturing fields. Fig1-1shows the problem which was contained in the level 3 test given in the summer of 2002 in which a schematic drawing showing an interior plan was presented in color. This question asked which color card is achromatic at the same value as the curtains (colored). This problem requires applicants to compare the luminosity of color chips they are presented with among color chips having different saturation and hue.

In addition, In the level 2 test given in the summer of 2004 (Fig1-2), four pairs of color cards were presented and instructions were given to indicate the appropriate cards for the combination of cards having the same hue, combination of cards having the same value and so forth. An excerpt of this question indicated with

Munsell symbols is shown in Table1. Examination of this question reveals that is it necessary to compare only value under conditions in which chroma, value and hue each differ. In addition, since the combination of value difference 1 is indicated as being incorrect, this means that the value difference of Munsell value 1 must be able to be discriminated.

The discrimination targeted by this study is discrimination under conditions in which none of the three attributes are constant as previously mentioned. As can be understood from the contents of the questions in color certification tests, this ability is considered to be required for persons engaged in color planning. However, there are currently no explanations relating to color discrimination such as the required level of discrimination ability or discrimination tending to be more difficult or easier depending on the type of color. At present, there are believed to be many cases in which such discrimination abilities relating to perception are typically acquired during the course of experience through practical application. This discrimination ability differs from that for which individual abilities are unable to be quantified in the manner of color coordination or color selection. Since three attributes are displayed with numerical values, discrimination ability can be determined quantitatively. As a result, it is believed to be possible to provide standards and develop a system relating to discrimination. The ultimate objective of this study is to develop this type of education program.

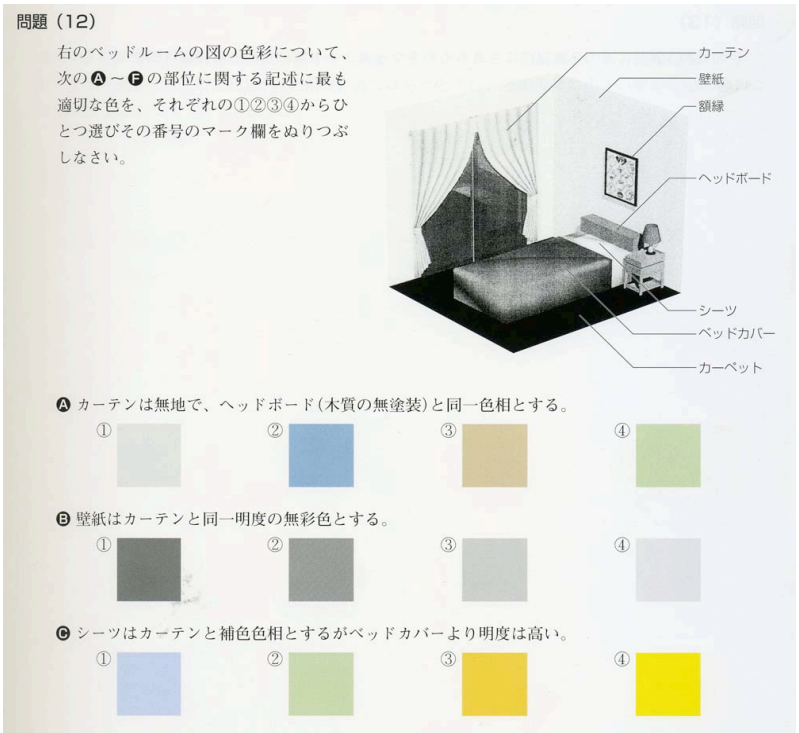
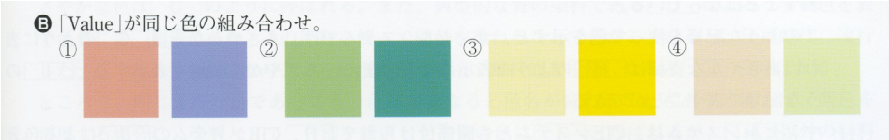


Fig.1-1 The discrimination question in the level 3 test.



	①	②	③	④
Left	4.0R/7.5/8	4.0G/8.0/6.5	5.0Y/9.0/3	8.0YR/9.0/3
Right	9.0PB/6.5/8	5.0BG/6.0/9	5.0Y/8.0/3.5	4.0GY/9.0/3

Fig.1-2 The discrimination question in the level 2 test. Correct answer is ④.

3 RELATED STUDY ON DISCRIMINATION ABILITY ORIENTED TOWARDS COLOR EDUCATION

Studies have been conducted focusing color discrimination from the viewpoint of education. Suzuki et al. conducted an experiment using a "New Color Ability Tester" to obtain basic data on color discrimination ability targeted at subjects having no previous color science experience (Suzuki et al.2004). The "New Color Ability Tester" is a training tool developed by the Japan Color Research Institute to improve color sense evaluation ability. According to the study report, the 3-point discrimination test and HVC discrimination test were conducted. In the 3-point discrimination test, one color card having a slightly different color is attempted to be distinguished from three color cards arranged in a row. In the HVC discrimination test, the colors of two color cards arranged in a row are slightly different, and an attempt is made to determine which attribute is responsible for the difference. Although this test is administered at beginner and advanced levels, since the differences in the color cards are very slight even at the beginner level, it has an extremely high level of difficulty. This experiment was conducted on persons who never studied color science and were inexperienced with respect to color. Based on the results of the experiment, individual differences in ability relating to discrimination were confirmed to be extremely large.

In addition, Yamagishi conducted an experiment targeted at discrimination under conditions in which the three attributes are not uniform entitled "Color Education Based on Color and Brightness" (Yamagishi et al. 2004). This experiment consisted of extracting 20 cards from color cards having various values, chroma and hue, and arranging the cards in order of decreasing value. The subjects were first made to perform this task and after being instructed regarding the correct and incorrect answers for those results, were made to perform the same task two months later followed by measurement of the effects of education. As a result,

there were reported to be numerous incorrect answers for "yellow approximating pure color", while there were hardly any mistakes in discriminating color cards in the "blue to green region". In addition, the "yellow to red region" and "color cards having low chroma" were determined to be color regions for which the effects of instruction were low. However, the experimental method used here seeks to determine the degree of error from a correct order, and does not involve a comparison with reference values. Accordingly, there is the risk of results being affected by mistaking other colors. Therefore, it was considered in this study to use a gray scale as a reference and quantify comparisons with this gray scale.

4. STUDY OF EXPERIMENT METHOD: CONDUCTING A PRELIMINARY EXPERIMENT

A experiment of this paper is a preliminary experiment to have the over all trends.

Experiment Overview: In this experiment, a gray scale was used as a reference point for measuring discrimination error. Subjects were asked to compare the value ratios of colored color cards using the gray scale as a reference followed by measurement of discrimination ability by numerically determining the error with correct answers.

Method: Eight colors ranging from achromatic N2 to N9 were placed in front of the subjects, colored color cards were randomly given one at a time to the subjects for each hue in the order of Y, R and PB, and the subjects were asked to answer by placing the color card next to the N color card they thought had the same value. In addition, the color cards were collected after each answer was given to avoid comparisons between colored color cards. For example, the error is evaluated as 1 in the case of having answered "N5" for a colored color card having a value of 6 (fig.1). As a result, the incorrect answer rate (correct answer rate) and maximum incorrect answer value were determined for each hue, after which incorrect and incorrect answer trends were similarly determined for value and chroma as well.

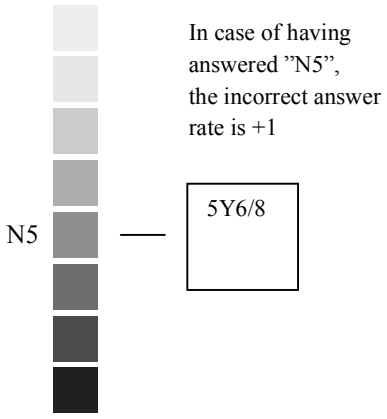
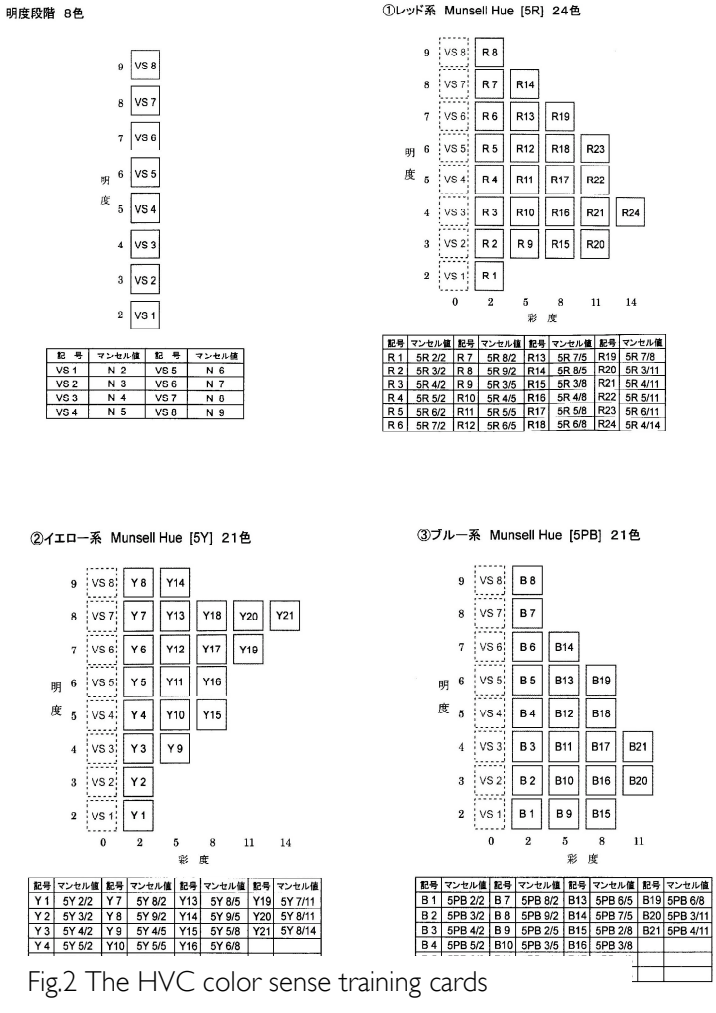


Fig.1 Answer Rate

Equipment: The HCV color sense training cards of the Japan Color Research Institute were used. These consist of 8 cards ranging from achromatic N2 to N9, 24 red cards having a Munsell hue of 5R, 21 yellow cards having a

Munsell hue of 5Y, and 21 blue cards having a Munsell hue of 5PB. Fig. 2 shows each color cards arranged in a hue cross-section and the Munsell values.



記号	マンセル値	記号	マンセル値
VS 1	N 2	VS 5	N 6
VS 2	N 3	VS 6	N 7
VS 3	N 4	VS 7	N 8
VS 4	N 5	VS 8	N 9

記号	マンセル値	記号	マンセル値	記号	マンセル値	記号	マンセル値
R 1	5R 2/2	R 7	5R 8/2	R13	5R 7/5	R19	5R 7/8
R 2	5R 3/2	R 8	5R 9/2	R14	5R 8/5	R20	5R 3/11
R 3	5R 4/2	R 9	5R 3/5	R15	5R 3/8	R21	5R 4/11
R 4	5R 5/2	R10	5R 4/5	R16	5R 4/8	R22	5R 5/11
R 5	5R 6/2	R11	5R 5/5	R17	5R 5/8	R23	5R 6/11
R 6	5R 7/2	R12	5R 6/5	R18	5R 6/8	R24	5R 4/14

記号	マンセル値	記号	マンセル値	記号	マンセル値	記号	マンセル値
Y 1	5Y 2/2	Y 7	5Y 8/2	Y13	5Y 8/5	Y19	5Y 7/11
Y 2	5Y 3/2	Y 8	5Y 9/2	Y14	5Y 9/5	Y20	5Y 8/11
Y 3	5Y 4/2	Y 9	5Y 4/5	Y15	5Y 5/8	Y21	5Y 8/14
Y 4	5Y 5/2	Y10	5Y 5/5	Y16	5Y 6/8		

記号	マンセル値	記号	マンセル値	記号	マンセル値	記号	マンセル値
B 1	5PB 2/2	B 7	5PB 8/2	B13	5PB 6/5	B19	5PB 6/8
B 2	5PB 3/2	B 8	5PB 9/2	B14	5PB 7/5	B20	5PB 3/11
B 3	5PB 4/2	B 9	5PB 2/5	B15	5PB 2/8	B21	5PB 4/11
B 4	5PB 5/2	B10	5PB 3/5	B16	5PB 3/8		

Fig.2 The HVC color sense training cards

Experiment Conditions: The experiment apparatus was fabricated based on JIS Z 8723 "Methods for visual comparison of surface colors" (Fig. 3). The CIE standard artificial daylight light source D65 was used for the light source, and the luminosity was set to about 1000 lx. The interior colors of the booth consisted of non-gloss, achromatic colors having a value of about N4 for the walls and a value of about N6 for the work surface.

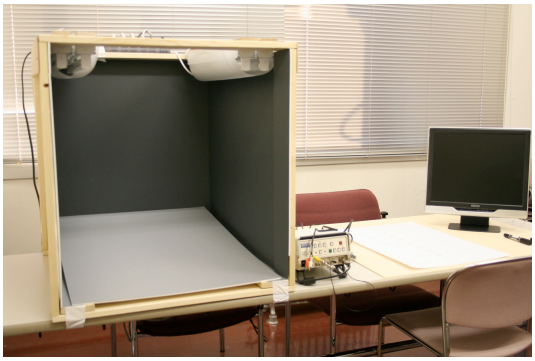


Fig.3 Experiment Conditions

Subjects: The subjects were selected to comprise a group of 11 subjects having experience relating to color, such as having practical training experience in color composition and so forth, having taken courses in color science or having been certified by a color certification test, and a group of 11 subjects having no practical training or classroom experience relating to color.

Contents of Survey:

1) Color sense test: This test was conducted using Ishihara's color plates for color blindness (generic name).

2) Correct answer rates, total correct answer rate and rank for each color, maximum error values and time required for each hue were investigated for each subject and for each color card.

3) The eye movements of the subjects were analyzed using an eye mark recorder during the experiment based on the possibility that differences may appear in eye movement during discrimination work between experienced subjects and inexperienced subjects.

5. RESULTS AND DISCUSSION

(1) As a result of the color sense test, the color sense of all subjects was confirmed to be normal.

(2) Table 2 shows the presence or absence of experience, correct answer rates, total correct answer rate and rank for each color, maximum error values and time required for each hue for each subject. Furthermore, the correct answer rate (a) refers to correct answers up to an error of 1 based on the Munsell value (this is because an error of 1 indicates only a slight error that closely approximates the correct answer, and if treated in the same manner as a considerably incorrect answer having an error of 2 or more, the overall trend is

unable to be accurately determined), while (b) refers to the completely correct answer. In addition, an asterisk next to a subject indicates that the subject has some form of qualification acquired by the color certification test and so on.

Table2. Results of the Experiment

		Y		R		PB							
	Experience	Correct (a)	(b)	Correct (a)	(b)	Correct (a)	(b)	Error Max	Correct Sum	Order	Y Time	R Time	PB Time
1	○	100.0	95.2	100.0	70.8	90.5	52.4	2	290.5	1	05:04	08:59	04:37
2*	○	95.2	57.1	91.7	58.3	90.5	38.1	5	277.4	3	04:07	05:03	03:48
3*	○	95.2	66.7	87.5	45.8	66.7	42.9	5	249.4	9	03:32	03:39	02:41
4	○	66.7	38.1	91.7	45.8	95.2	52.4	6	253.6	6	04:40	03:54	03:37
5	○	71.4	38.1	79.2	45.8	100.0	66.7	4	250.6	8	06:03	07:30	05:00
6*	○	81.0	19.0	79.2	16.7	76.2	52.4	6	236.3	13	05:30	06:05	06:54
7	○	71.4	23.8	87.5	54.2	95.2	38.1	4	254.2	5	02:48	02:53	02:39
8	○	42.9	14.3	87.5	45.8	95.2	66.7	6	225.6	16	04:23	04:36	03:19
9*	○	95.2	76.2	83.3	20.8	38.1	14.3	6	216.7	17	04:35	05:18	04:21
10	○	85.7	52.4	75.0	37.5	76.2	47.6	4	236.9	12	02:58	03:26	02:44
11	○	100.0	42.9	79.2	50.0	66.7	33.3	4	245.8	11	06:43	09:01	12:24
12	/	42.9	19.0	83.3	37.5	100.0	71.4	5	226.2	15	02:13	02:00	01:47
13	/	76.2	28.6	66.7	20.8	85.7	38.1	4	228.6	14	01:34	01:31	01:18
14	/	100.0	52.4	87.5	54.2	90.5	52.4	4	278.0	2	07:48	06:35	05:45
15	/	52.4	19.0	79.2	33.3	76.2	28.6	6	207.7	18	03:51	03:17	02:34
16	/	76.2	42.9	75.0	33.3	47.6	9.5	5	198.8	22	02:45	02:08	02:12
17	/	57.1	19.0	70.8	37.5	71.4	33.3	4	199.4	20	02:35	02:35	02:11
18	/	85.7	52.4	75.0	29.2	90.5	61.9	5	251.2	7	06:46	12:28	11:36
19	/	66.7	33.3	70.8	25.0	61.9	28.6	6	199.4	21	05:30	04:27	03:21
20	/	76.2	52.4	95.8	50.0	100.0	61.9	5	272.0	4	04:13	03:50	04:00
21	/	81.0	23.8	91.7	62.5	76.2	57.1	6	248.8	10	05:22	03:49	02:42
22	/	38.1	4.8	75.0	16.7	90.5	38.1	5	203.6	19	01:28	01:20	01:08

・Correct Answer Rates According to Subject and Hue:

When the correlation between hue and correct answer rates was tested using a non-parametric analysis, a statistically significant difference was not obtained ($p>0.05$). However, when focusing on the experienced group (Nos. 1 to 11), those subjects exhibiting a high correct answer rate for blue exhibited a low correct answer rate for yellow, while those subjects exhibiting a high correct answer rate for yellow exhibited a low correct answer rate for blue, thereby dividing the group into two subgroups having opposite correct answer trends (in the table, the hue for which the correct answer rate was the highest for each subject is indicated in red, while the hue having the lowest correct answer rate is indicated in blue). This trend was not observed among inexperienced subjects.

In interviews conducted after the experiment, the following replies were given by members of the experienced group regarding the sense of difficulty for each hue: hues for which discrimination was difficult: Y: 3 subjects, R: 1 subject, PB: 6 subjects; hues for which discrimination was easy: Y: 4 subjects, R: 3 subjects, PB: 3 subjects; and, hues discriminated with equal difficulty: 1 subject. Among subjects of the inexperienced group, the replies were as follows: hues for which discrimination was difficult: Y: 4 subjects, R: 1 subject, PB: 2 subjects; hues for which discrimination was easy: Y: 2 subjects, R: 4 subjects, PB: 1 subject; and, hues discriminated with equal difficulty: 4 subjects.

On the basis of these findings, it was determined that those hues for which discrimination is felt to be difficult vary depending on the individual, and that among subjects of the inexperienced group, there is comparatively large number of subjects who did not sense any differences in difficulty.

Ease or difficulty in discrimination attributable to differences in hue was confirmed based on experiment results and replies from interviews. However, there was no common hue that caused the greatest difficulty among the subjects, thus demonstrating that difficulties in discrimination according to hue vary depending on the particular individual.

・Chroma, Correct Answer Rates and Absolute Values of Maximum Error

A significant difference was observed for each hue with respect to the relationship between chroma and correct answer rates ($p<0.001$ for Y, R and B). Fig. 4 is a table in the form of a distribution diagram plotting chroma Munsell values on the horizontal axis and correct answer rates on the vertical axis. In looking at these values, chroma and correct answer rates can be seen to exhibit a negative correlation. In addition, Fig. 5 plots the absolute value of maximum error on the vertical axis, and the larger this value, the greater the range of

incorrect answers. In this figure, the maximum value of error increases the larger the chroma Munsell value for each hue. In addition, in looking at both figures according to each hue, a trend can be seen in which correct answer rates are high and the range of error is small for R.

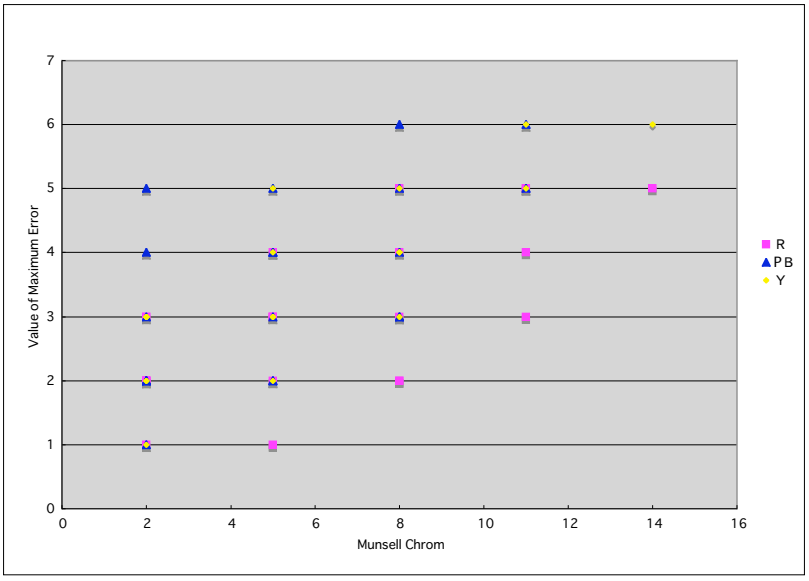


Fig. 4 Value of Maximum Error and Munsell Chroma

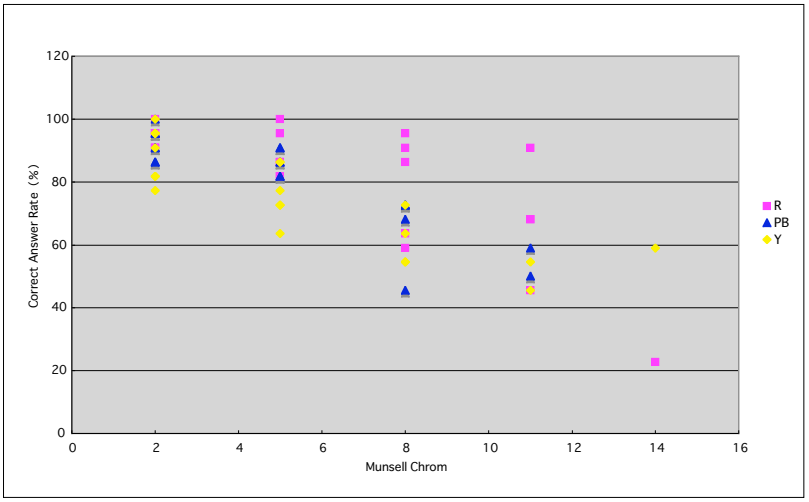


Fig. 5 Correct Answer Rates and Munsell Chroma

・Value and Correct Answer Rates

There were no statistically significant differences observed between value and correct answer rates. Discrimination difficulty is not thought to be related to value. However, the possibility remains of the existence of a correlation in the case of grouping the subjects in the same manner as the correct answer rates according to hue of the previous section.

・Required Time

A comparison of the required times for the three hues for each subject revealed that B tended to require the shortest amount of time. Since the experiment was conducted in the order of Y, R and B, the results may have been affected by familiarity with the order of the experiment.

(3) Survey Using Eye Mark Recorder

An eye mark recorder was used on the subjects during this experiment based n the possibility of differences in eye movement appearing when performing a comparative discrimination tasks between experienced subjects and inexperienced subjects. Subjects having the highest correct answer rates compared the target color cards while moving their eyes in line with the gray scale, and the distance of movement of their line of sight was small(fig.6). Subjects having low correct answer rates held the color cards in their hands and compared them with the gray scale on the workbench, and the distance between color cards being compared as well as the distance of movement of their line of sight both tended to be large (fig.7). This suggests that subjects having high correct answer rates understood how to look at the color cards during the course of the discrimination task, and looked at the color cards in a manner that made the comparison task easier. Subjects having low correct answer rates tended to spend less time on the task overall, and frequency replied in the interviews that they simply compared the color cards intuitively. On the basis of these findings, it is presumed that they had not determined the proper way to compare the attribute of value.

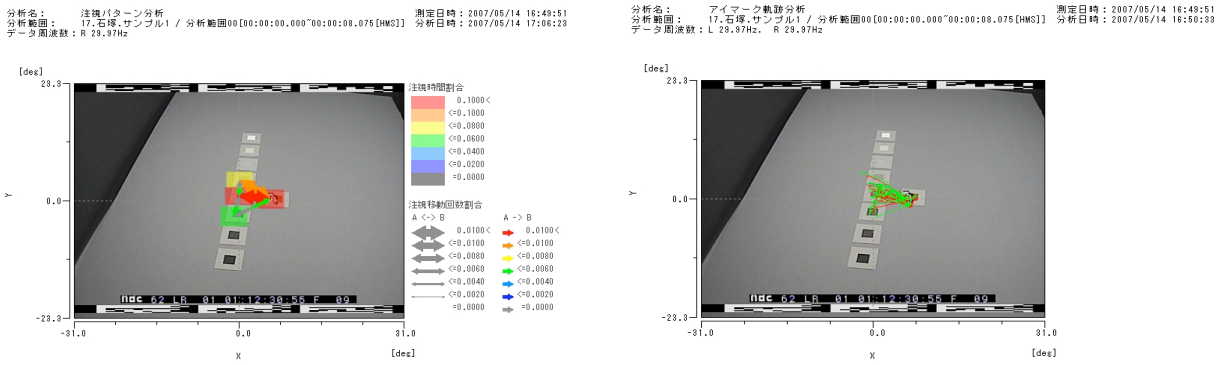


Fig.6 A subject having the highest correct answer rates

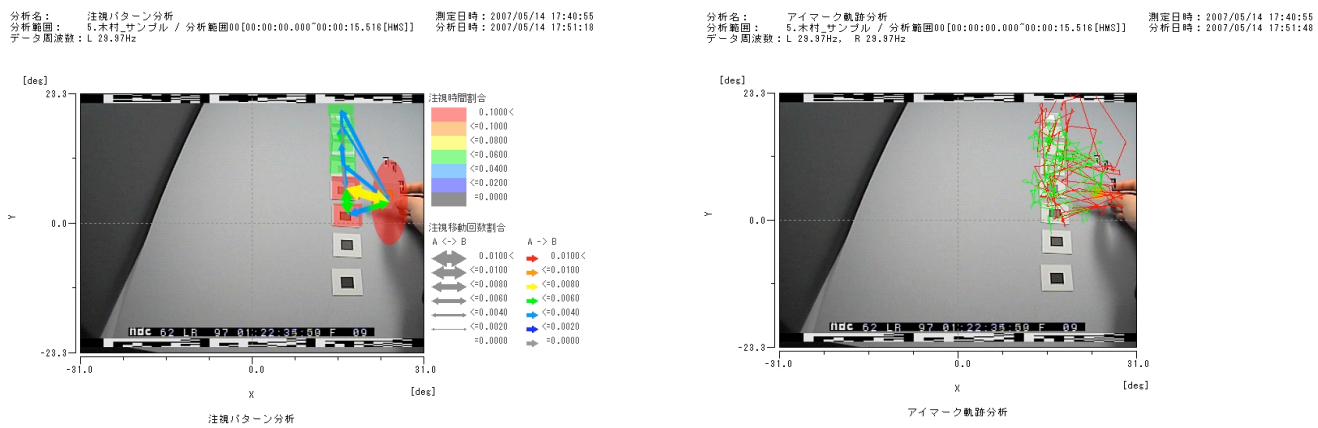


Fig.7 A subject having low correct answer rates

6. CONCLUSION

The following findings were obtained from the investigative experiment conducted in this study.

Overall, error was confirmed to have increased as chroma became higher, and the range of that error also increased.

With the exception of one subject who demonstrated the best score, the maximum value of error with the correct answers was at a Munsell value of 4 to 6. Since value numbers range from 2 to 9, this error can be judged to be extremely large. When considering that the subjects included qualified persons certified by a

color certification test, it would probably be desirable to examine standard values and the manner in which color skills are acquired.

Subjects having experience relating to color, such as subjects who have taken courses in color science or have been certified by a color certification test, did not necessarily rank high for discrimination ability. In addition, although many of the inexperienced subjects were ranked low, there were some inexperienced subjects who demonstrated extremely high correct answer rates.

Background as related to color may also be able to be correlated to those factors responsible for discrimination ability. It is therefore necessary to confirm this correlation by conducting experiments while also considering the profiles of the subjects.

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