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Centroids of Color Categories Compared by Two Methods

A procedure is described whereby the subset of Munsell colors of maximum chroma, which has been used by anthropologists to study color naming since Berlin and Kay in 1969, can be specified in the L,j,g *coordinate system developed more recently by the Uniform Color Scales Committee of the Optical Society of America. The latter permits a meaningful specification of the centroid location of colors named by each basic term. The procedure is validated by comparing centroids obtained from six subjects who named samples of both the Munsell and OSA sets, and its usefulness is illustrated by comparing data from a four-year old who named only OSA samples and four- and two-year-olds who named only Munsell colors.*

Introduction

In studies undertaken for cross-linguistic comparison of color categorization in indigenous Mesoamerica, MacLaury[1,2] used a set of Munsell color samples that were equivalent (except for the addition of an extra achromatic step) to those introduced nearly 20 years ago by Berlin and Kay[3] in their pioneering cross-cultural study of basic color terms. MacLaury's set consists of 330 color chips that include the most saturated samples of 40 hues at 8 lightness levels, plus 10 chips in the achromatic series running from black to white through a series of intermediate grays.

TABLE I. Sex, age, Japanese prefecture of origin, and number of color terms used by the six subjects of the study.

Subject	Sex	Age	N	Prefecture of origin	Lighting
KM	F	39	50	Fukuoka	Outdoor
HY	M	40	32	Shizuoka	Outdoor
NK	M	31	30	Yamaguchi	100-W bulb
KH	F	34	30	Iwate	Outdoor
YK	F	31	24	Kanagawa	Outdoor
MI	M	39	16	Tokushima	Outdoor

Our surface-color research in La Jolla[4,5] has employed instead 424 color samples of a set developed by the Uniform Color Scales Committee of the Optical Society of America (OSA). The OSA color chips were designed to sample 3-dimensional subjective color space uniformly. The set includes many colors of low saturation that have no counterpart in the Berlin-Kay-MacLaury subset of Munsell colors.

Given the large body of anthropological data obtained with the Munsell chips, we felt that a comparison of our two methods using the same subjects would be useful. Uchikawa and Boynton[5] published a study of 10 native Japanese subjects using the OSA chips. We were able to schedule six of this group to be tested by MacLaury's method. Table I gives information about the subjects and the conditions of testing with the Munsell chips.

Both testing procedures require subjects to name color samples presented in a random order, but otherwise there are important differences. The OSA chips were seen by subjects under well-controlled conditions of illumination. Most of the visual field was filled with a standard gray of 20% reflectance, and the OSA chips were viewed within a square aperture, 38 mm on a side, at a distance of 650 mm. Samples were illuminated by a 3200 K tungsten source that provided 40 cd/m^2 of luminance from the gray background. The colors were always presented in a specific location for which the specular component of reflection was negligible. Each chip was seen twice, and a different random order of presentation was used for each subject.

MacLaury's method differed from what has just been described in the following respects: (a) To enable storage in a restricted space and to withstand handling under the varied and often difficult conditions of field studies, MacLaury's samples are smaller (approximately 20 $\times$ 25 mm), and are individually mounted on a slightly larger small gray background, laminated in plastic. (b) Color chips were viewed in a natural setting against whatever extended background happened to be present, usually out-of-doors but sometimes under artificial illumination. (c) The experimenter presented the samples by hand in a relatively uncontrolled fashion. (d) There were somewhat fewer restrictions on the color names that were allowed. Whereas monolexemic color naming was strictly observed using the OSA samples, compound terms like *kimidori* (yellow-green) were permitted using the Munsell chips. (Modifiers like *ki* were ignored in analyzing the data to be reported here.) (e) The same order of presentation was used for all subjects, and the samples were seen only once each. (f) There was a second phase of the testing procedure designed to identify choices of category foci, and a third that measured regions over which color terms volunteered in the first phase seemed appropriate.

Based on the OSA method, a centroid location corresponding to each color term can be calculated. The centroid represents the middle of the set of color chips named with that term. Such an average in the Munsell system would not be meaningful, because equal steps between all adjacent pairs of samples are not represented. For example, as chroma increases, step sizes between adjacent chips around the hue circle must increase because of their fixed number; moreover, the three dimensions of the cylindrical space must be weighted differently in calculating color differences, and there is no agreement about how best to do this.[6]

The approach taken here in an attempt to reconcile data using the two procedures is the following: (a) Find the OSA chip that most closely matches each of the Munsell chips. (b) Using the experimental data obtained using OSA chips in the observation booth, determine centroids for the resulting subset of OSA chips so that these may be compared with those for the full set. (c) Using the experimental data obtained with the Munsell chips in a natural

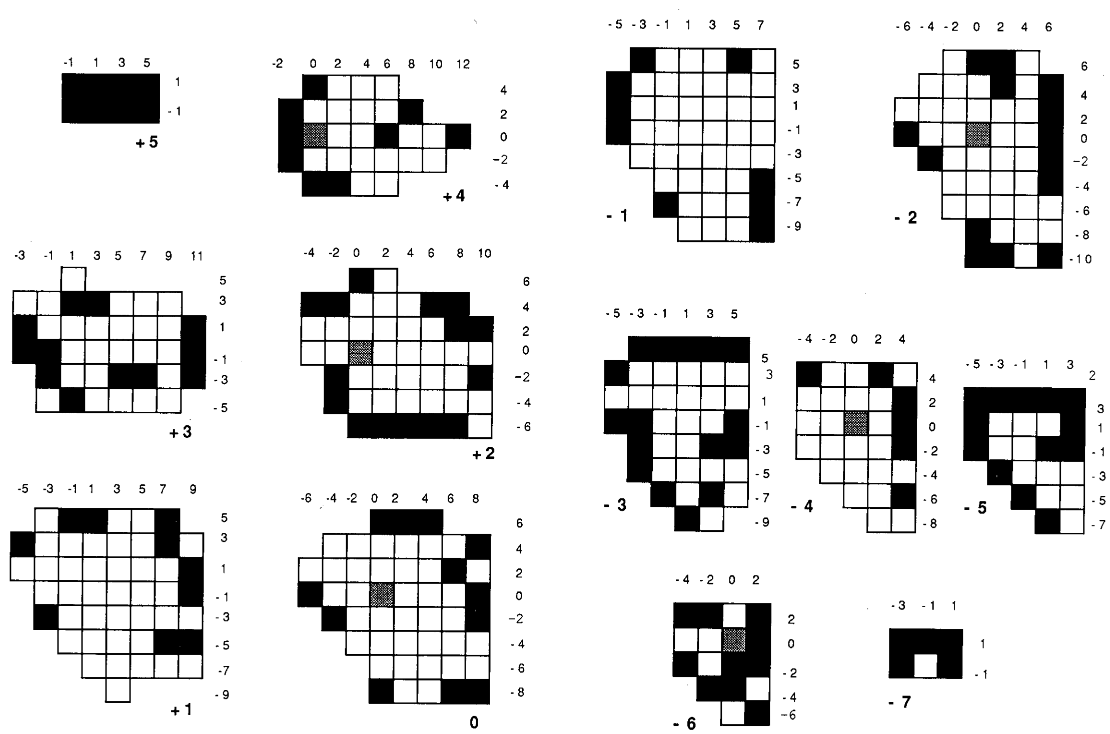

FIG. 1. Location of OSA samples (black squares) for which there is a matching Munsell chip from the Berlin-Kay-MacLaury Munsell set. These are displayed within equal-lightness planes of the OSA system ranging from +5 to −7. Within each lightness level, values of *j* are plotted horizontally and values of *g* are indicated vertically. There is no matching Munsell chip corresponding to the OSA samples represented by the white squares. Stippled squares represent matching grays.

TABLE II. Multiple pairings of many Munsell chips, each with the same OSA color.

No. of Munsell chips matching the same OSA chip	Frequency	Total number of matches
2	51	102
3	17	51
4	12	48
5	6	30
6	1	6
7	0	0
8	2	16
9	1	9
10	1	10
Grand totals	91	272

setting, determine centroids based on the OSA subset of samples that match the chips of the Munsell set.

Finding the Matching Chips

Based on the product of 424 OSA and 330 Munsell chips, there are 139,920 possible pairs that might match. Strictly speaking, all of these must be considered in order to find matching pairs between the two sets.

Visual Comparisons

The OSA samples[7] are mounted in 22 plastic "pages" of the kind ordinarily used to store 4 × 5 arrays of 35-mm slides. The plastic covering the OSA chips has a density equivalent, by visual inspection, to that within which the Munsell samples are permanently laminated. Using MacLaury's standard presentation order, one of us compared each Munsell chip in turn with the samples of the OSA set, which remained within their plastic inserts, ordered in lightness from top to bottom on each page. The comparisons were made under illumination from the same type of 200-W, 3200 K incandescent photoflood source that was used by Uchikawa and Boynton. (Many matching pairs were subsequently compared in sunlight, skylight, and under the illumination from a 60-watt lamp, and the matches did not fail, suggesting that metamerism is not great between the Munsell and OSA sets.)

For every chip in the MacLaury set, the OSA sample judged to be a best match was determined, the OSA coordinates were recorded, and the Munsell chip was returned to the storage box. When the matching was done, an ordered list of the OSA samples was prepared, and next to each was written the Munsell H/V/C coordinates for the matching samples.

Of the 424 OSA samples, 145 were paired with at least one Munsell chip. Six of these pairings were in the gray series. Otherwise, as Fig. 1 shows, the matching set of 139 OSA chromatic samples is limited to a subset of those that lie on or near the outside of the OSA color planes at each lightness level. Most of the Munsell chips unpaired with one from the OSA set were eliminated because of multiple matches of Munsell chips with the same OSA sample. There were many of these, distributed as shown in Table II, from which a single Munsell chip had to be selected after additional comparisons had been made (see below). This led to the rejection of 181 Munsell chips. In a few cases, limited to the highest lightness levels, a Munsell chip was rejected because the spacing of the OSA samples was too coarse to find a reasonable match.

Calculated Matches

Nickerson[8] calculated Munsell equivalents for the set of OSA color samples that had been measured spectrophotometrically by MacAdam.[9] Using her data, difference scores for H, C, and V were computed between Nickerson's data for the matching OSA sample and specifications of the Munsell chips matched to them.

On most occasions when more than one Munsell chip was paired with an OSA sample, the visual choice corresponded to the smallest calculated difference. Of the several formulas that have been proposed for making such calculations,[6] we used Nickerson's[10] "Index of Fading" (hereafter the Nickerson Index), which is the simplest of such methods. The Nickerson Index equals $0.4C\ \Delta H + 6\ \Delta V + 3\ \Delta C$, where ΔH, ΔV, and ΔC are the absolute differences of H, V, and C, respectively, between the Nickerson-Munsell specification of an OSA chip and that of the Munsell chip matched to it. (In making the calculations, the value of C for the OSA sample has been used in the first term of the equation.)

When the difference exists in only one of the three Munsell dimensions, all calculation methods make the same predictions. For example, OSA sample, $L,j,g = -4,4,2$, which according to Nickerson is equivalent to $H/V/C$ = 7.2GY/4.08/5.7, was matched by three Munsell chips visually paired with it; the Munsell deviations from the target chip, were:

Munsell	H/V/C difference	Nickerson Index
5GY/4/8	2.2/0.08/2.3	12.40
7.5GY/4/8*	0.3/0.08/2.3	8.06
10GY/4/8	2.8/0.08/2.3	13.76

The middle chip, whose Munsell specification is marked with the asterisk, is the one that had been chosen as the best visual match, as well as the closest match by any reasonable calculation. Sometimes, in such cases, there was a clear disagreement with the visual match. Most of the time, when a disagreement occurred, the visually matching chip was selected anyway. The calculated match was adopted instead when (a) the visual choice had been a difficult one, (b) a different choice was clearly indicated by the HVC-difference calculation, and (c) the resulting pair seemed, upon additional inspection, to form about as good a match as the one previously selected.

Calculated differences become more complicated when two or more dimensions differ. As an example, consider

TABLE III. Pairings of 145 OSA and Munsell chips. The first column shows the *L,j,g* coordinates of the OSA chip. The second column shows the *H,V,C* coordinates of the Munsell chip selected as the best match to the OSA chip. The third column shows, for the OSA chip, the equivalent *H,V,C* coordinates in the Munsell system, based on Nickerson's calculations. The rightmost column gives the Nickerson Index of Fading.

OSA coordinates			OSA Munsell equivalents			Paired sample			Nickerson Index of Fading
L	*j*	*g*	*H*	*V*	*C*	*H*	*V*	*C*	
−7	−3	−1	7.5P	2	6	6.0PB	2.08	4.9	6.72
−7	−3	1	7.5BP	2	10	9.0PB	2.08	4.9	18.72
−7	−1	1	10BG	2	4	9.7B	2.00	1.8	13.58
−7	1	−1	7.5YR	2	4	6.0YR	2.42	1.3	11.40
−7	1	1	10GY	2	4	0.6G	2.16	2.5	6.06
−6	−4	2	5BP	2	8	5.2BP	2.56	6.6	8.09
−6	−2	−4	7.5RP	2	8	4.6RP	2.65	7.1	14.84
−6	−2	−1	10P	2	6	0.6RP	2.77	4.6	9.92
−6	−2	2	5B	2	4	0.9PB	2.68	3.8	13.65
−6	0	−4	7.5R	2	8	10.0R	2.69	5.9	28.78
−6	0	−2	10R	2	6	0.8R	2.78	2.6	24.45
−6	0	0		N3					1.80
−6	2	−6	10R	3	10	6.1R	2.89	7.3	20.15
−6	2	−2	7.5R	3	6	5.4R	2.89	3.3	11.27
−6	2	0	2.5GY	3	4	1.3GY	3.03	2.1	6.89
−6	2	2	7.5GY	3	6	1.9RP	4.20	9.6	14.40
−5	−5	−1	10BP	3	10	0.1P	2.91	7.6	8.04
−5	−5	1	7.5PB	3	12	7.3PB	2.97	8.2	12.24
−5	−5	3	5BP	3	10	5.0PB	2.82	8.5	5.58
−5	−3	−3	7.5P	3	10	5.0P	3.49	7.6	17.74
−5	−3	3	7.5B	3	6	1.4PB	2.95	5.9	9.80
−5	−1	−5	7.5RP	3	10	6.6RP	3.24	7.4	11.90
−5	−1	3	10BG	3	6	2.2B	3.19	4.1	10.45
−5	1	−7	2.5R	3	10	2.9R	3.14	9.1	5.00
−5	1	−1	7.5Y	3	4	6.0YR	3.55	1.2	17.22
−5	1	3	7.5G	3	8	8.9G	3.30	5.1	13.36
−5	3	−1	5Y	3	4	3.1Y	3.48	3.1	7.94
−5	3	1	5GY	3	10	5.7GY	3.43	3.8	22.24
−5	3	3	10GY	3	8	1.4G	3.42	5.8	12.37
−4	−4	4	10B	3	8	1.1PB	3.52	7.8	7.15
−4	0	0		N4					1.96
−4	2	4	5G	4	10	4.1G	4.06	6.1	14.26
−4	4	4	2.5YR	4	10	0.6YR	3.85	8.3	11.71
−4	4	−2	10YR	4	6	0.1Y	4.05	4.8	4.09
−4	4	0	10Y	4	6	0.4GY	4.12	4.2	6.79
−4	4	2	7.5GY	4	8	7.2GY	4.08	5.7	8.06
−3	−5	−1	2.5P	4	10	0.6P	4.15	8.5	11.86
−3	−5	3	2.5BP	4	10	3.2PB	4.11	8.1	8.63
−3	−3	−5	2.5RP	4	12	1.4G	3.42	5.8	23.47
−3	−3	−3	7.5P	5	10	8.2P	4.30	7.2	14.62
−3	−3	−1	5P	4	10	3.3P	4.30	5.3	19.50
−3	−3	5	7.5B	4	8	6.1B	4.12	7.0	7.64
−3	−1	−7	10RP	4	14	7.3RP	4.27	10.4	23.65
−3	−1	5	10BG	4	6	7.8BG	4.24	6.4	8.27
−3	1	−9	5R	4	14	2.2R	4.26	11.8	19.02
−3	1	5	10G	4	3	9.4G	4.41	7.0	16.14
−3	3	−7	10R	4	14	6.2R	4.38	9.7	25.80
−3	3	−3	5YR	4	8	3.9YR	4.00	8.0	17.20
−3	3	5	2.5G	4	10	2.7G	4.59	8.2	9.60
−3	5	−3	7.5YR	4	8	9.5YR	4.50	6.5	12.70
−3	5	−1	7.5Y	5	8	5.1Y	4.79	5.3	14.45
−3	5	5	2.5G	5	12	1.0G	4.73	9.2	15.54
−2	−6	0	10BP	5	10	8.7PB	4.5	9.6	9.19
−2	−4	−2	7.5P	4	10	7.9RP	6.87	8.4	21.32
−2	−2	−6	5RP	5	12	4.2RP	4.82	9.7	11.14
−2	0	−10	10RP	5	14	9.6RP	4.71	12.3	8.81
−2	0	−8	7.5RP	5	12	9.4RP	4.77	11.0	12.74
−2	0	0		N5					0.24
−2	0	6	5BG	5	8	4.8BG	4.90	7.4	2.99
−2	−2	−10	5R	5	14	3.7R	4.75	12.7	12.00
−2	2	4	10G	5	10	6.2G	5.02	6.2	20.94
−2	2	6	7.5G	5	10	8.5G	5.01	8.3	8.48
−2	6	−10	7.5R	5	14	8.9R	4.78	14.8	12.01
−2	6	−4	7.5YR	5	10	6.5YR	5.00	8.6	7.64
−2	6	0	10Y	5	8	8.6GY	5.31	6.1	10.98
−2	6	2	5GY	5	10	5.4GY	5.44	7.3	11.91
−2	6	4	7.5GY	5	10	8.9GY	5.25	8.7	10.27

Continued

TABLE III. Continued

OSA coordinates			OSA Munsell equivalents			Paired sample			Nickerson Index of Fading
L	j	g	H	V	C	H	V	C	
−1	−5	−1	2.5P	5	10	6.9PB	5.20	8.3	24.89
−1	−5	1	7.5BP	5	10	6.9PB	5.20	8.3	9.20
−1	−5	3	5BP	5	12	9.6B	4.58	7.7	32.05
−1	−3	5	5B	5	8	4.4B	5.26	7.3	5.41
−1	−1	−7	5RP	6	12	6.4RP	5.4	10.3	14.47
−1	5	5	10GY	6	10	9.4G	4.41	7.0	27.22
−1	7	−9	10R	5	16	9.2R	5.23	14.9	9.45
−1	7	−7	2.5YR	5	14	2.5YR	5.26	11.8	8.16
−1	7	−5	7.5YR	6	14	5.7YR	5.55	10.5	24.96
0	−6	0	10BP	6	8	9.5PB	5.41	8.9	8.02
0	−4	−2	5P	6	8	4.1P	5.65	6.8	8.15
0	0	−8	10RP	6	12	9.0RP	5.86	10.2	10.32
0	0	0		N6					0.01
0	0	6	5BG	6	8	4.4BG	5.87	7.6	3.20
0	2	6	7.5G	6	10	7.3G	5.89	8.7	5.26
0	4	6	2.5G	6	10	2.7G	5.94	9.2	3.50
0	6	−8	10R	6	14	2.6YR	5.98	10.1	22.32
0	6	2	2.5GY	6	10	5.1GY	6.31	6.6	18.40
0	8	−8	2.5YR	6	16	3.1YR	5.96	13.6	10.70
0	8	−2	2.5Y	6	10	2.5Y	6.14	9.0	3.84
0	8	0	10Y	6	10	7.7Y	6.21	8.0	14.62
0	8	4	5GY	6	8	6.8GY	6.28	10.1	14.65
1	−5	3	2.5BP	6	10	3.3PB	5.99	8.2	7.76
1	−3	−3	10P	6	10	8.0P	6.21	6.9	16.08
1	−1	−5	7.5BG	6	8	4.9RP	6.34	7.8	29.70
1	1	5	10G	7	8	0.9BG	6.45	6.4	10.40
1	7	−5	5YR	6	12	4.9YR	6.53	9.9	9.88
1	7	3	7.5GY	7	10	6.1GY	6.84	7.9	11.68
1	7	5	7.5GY	6	12	8.9GY	6.68	9.8	16.17
1	9	−5	7.5YR	7	14	6.5YR	6.54	11.6	14.60
1	9	−1	5Y	7	12	5.3Y	6.74	9.2	11.06
1	9	1	10Y	7	12	0.4GY	6.77	8.8	12.39
2	−4	4	10B	7	8	0.3PB	6.56	7.3	5.62
2	−2	−4	2.5RP	6	10	2.4RP	6.72	7.1	13.30
2	−2	−2	7.5P	7	8	7.9P	6.84	5.3	9.91
2	−2	4	5B	7	6	4.0B	6.83	5.4	4.98
2	0	−6	7.5RP	7	10	7.9RP	6.87	8.4	6.92
2	0	0		N7					0.78
2	0	6	5BG	7	8	5.0BG	6.94	7.3	2.46
2	2	−6	5R	7	8	4.4R	6.93	7.8	2.89
2	4	−6	10R	7	10	9.3R	7.01	8.5	6.94
2	6	−6	2.5R	7	10	2.4YR	6.99	9.8	1.05
2	6	4	10GY	7	10	8.8GY	7.33	7.8	12.32
2	8	−6	5YR	7	14	4.4YR	6.94	11.3	14.17
2	8	2	5GY	7	6	3.8GY	7.45	8.0	12.54
2	8	4	7.5GY	8	10	6.7GY	7.36	9.4	8.65
2	10	−2	2.5Y	7	12	2.5Y	7.29	11.0	4.74
2	10	2	2.5GY	7	12	2.2GY	7.41	10.1	11.40
3	3	−1	2.5P	7	6	4.7P	7.33	4.8	9.80
3	−3	1	5BP	8	6	5.6BP	7.35	5.0	8.10
3	−1	−3	2.5RP	8	6	3.4RP	7.47	5.3	7.19
3	−1	−1	2.5P	8	4	7.6P	7.54	2.9	11.98
3	1	−5	5R	8	6	2.0R	7.50	6.9	13.98
3	1	3	10G	8	6	8.4G	7.62	3.9	11.08
3	3	3	2.5G	8	8	1.4G	7.72	4.5	14.16
3	5	−3	5YR	8	6	6.8YR	7.75	6.2	6.56
3	7	−3	7.5YR	8	8	9.1YR	7.83	7.9	6.38
3	11	−3	10YR	8	14	0.9Y	7.92	13.0	8.16
3	11	−1	5Y	8	14	4.1Y	7.79	11.4	13.16
3	11	1	10Y	8	12	9.6Y	8.01	11.0	4.82
4	−2	−2	7.5P	8	6	6.8P	8.00	4.0	7.12
4	−2	0	10PB	8	4	9.0PB	8.00	3.5	2.90
4	−2	2	2.5PB	8	6	0.3PB	8.04	3.8	10.18
4	0	−4	2.5R	8	6	2.0R	7.50	6.9	7.08
4	0	0		N8					0.90
4	0	4	5BG	8	4	5.1BG	7.87	4.2	2.15
4	2	−4	7.5R	8	6	7.4R	8.06	5.2	2.97
4	6	0	10Y	9	6	7.7Y	8.46	5.1	10.63
4	8	2	5GY	8	4	3.3GY	8.44	7.3	17.50

Continued

TABLE III. Continued

OSA coordinates			OSA Munsell equivalents			Paired sample			Nickerson Index of Fading
L	j	g	H	V	C	H	V	C	
4	12	0	7.5Y	8	12	6.6Y	8.41	12.3	9.26
5	−1	−1	7.5P	9	2	7.2P	8.57	2.8	5.32
5	−1	1	10B	9	2	1.7PB	8.61	2.5	5.54
5	1	−1	5YR	9	2	4.0YR	8.77	1.7	2.96
5	1	1	10GY	9	2	0.9G	7.64	1.4	10.02
5	3	−1	10YR	9	8	9.9YR	8.86	2.7	16.85
5	3	1	7.5GY	9	2	6.1GY	8.92	2.4	3.02
5	5	−1	5Y	9	6	3.4Y	8.92	4.4	8.10
5	5	1	5GY	9	2	2.3GY	8.97	4.0	10.50

the following situation in which all three dimensions differed between the OSA Munsell equivalent and each of two matching samples. The OSA sample was 4,8,2, equivalent to 3.3GY/8.44/7.3, and two Munsell samples were matched to it.

In this example, shown below, Munsell chip 5GY/8/4, with the larger Nickerson Index, was nevertheless judged as a better match to the OSA sample and was retained.

Munsell	H/V/C difference	Nickerson Index
2.5GY/9/6	0.8/0.56/1.3	9.60
5GY/8/4*	1.7/0.44/3.3	17.50

Summary of Chips Selected

Table III lists the L,j,g coordinates of the 145 chromatic OSA samples selected, their equivalent Munsell values, the H/V/C values of the paired Munsell chip, and the Nickerson Index of the difference between the ideal Munsell matching sample and the one actually chosen. Figure 2 shows frequency distributions of the H, V, and C difference scores based on the data of Table III.

Discussion (Matches)

The Munsell colors are known to include more saturated examples than does the OSA set. The data bear this out, showing that the mismatch for chroma is in the expected direction 89 percent of the time. In making matches, the excess chroma of the Munsell chips, although generally evident, did not seem to be a serious problem.

The set of 139 chromatic Munsell samples can now be regarded as having an equivalent designation in the OSA system. They constitute 42% of the Munsell samples used by MacLaury and 33% of the OSA samples. The results also show good agreement concerning what is defined as chromatically neutral in the two systems. Table III shows that six (out of ten) neutral Munsell samples form the best matches with OSA chips that plot at $j = g = 0$ at the even lightness levels ($L = -6, -4, -2, 0, +2,$ and $+4$).

Except for reasonably consistent relations between L in the OSA system and V in the Munsell, a comparison of the OSA designations as they are spread across the columns and rows of ordered Munsell coordinates is not very illuminating other than to reveal just how different these two systems of color ordering are. Figure 3 shows the subset of chosen Munsell samples, arrayed this time in the Berlin-Kay manner. Consider as an example the 7.5 GY column which is filled with OSA matches from level 9 to level 3: The corresponding OSA specifications are 5,3,1; 4,8,2; 1,7,3; 1,7,5; −2,6,4; −4,4,2; and −6,2,2. Or, reading horizontally across the $V = 8$ row from 2.5R to 10YR: 4,0,−4; 3,1,−5; 4,2,−4; blank; blank; 3,5,−3; 3,7,−3; 3,11,−3. The convergence of multiple Munsell values upon very few OSA values at high and very low lightnesses is another indication of the difference between the sampling of color space represented by the two systems; it is an inevitable

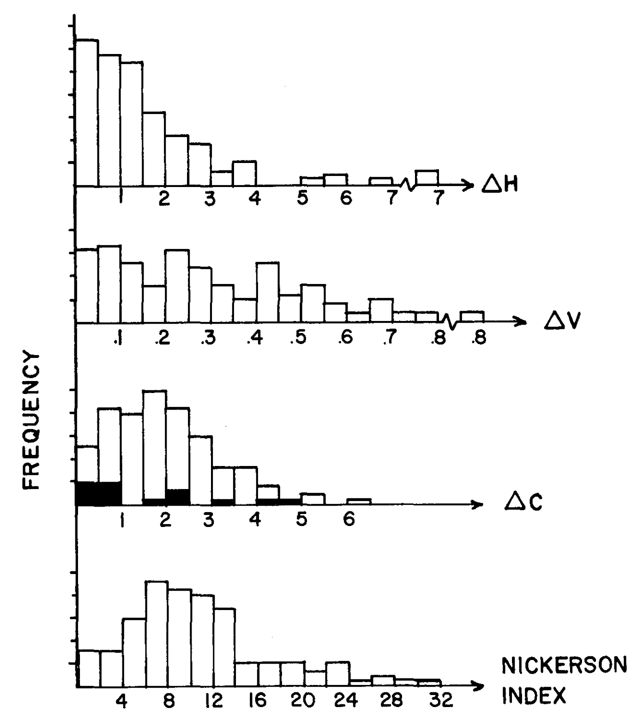

FIG. 2. Frequency distributions of H, V, and C difference scores, and of the Nickerson index of color difference, between Nickerson's Munsell equivalents and matching samples. Filled portions of ΔC bars represent the minority of cases where the OSA chip was of higher chroma than the matching Munsell sample.

TABLE IV. Each of the eight columns of Japanese terms name one basic color category, defined in English at the top. In each column, the first Japanese word is the basic term for the category, followed by names that have been treated as equivalents, based on the study of Uchikawa and Boynton[5]. White, black, and gray are omitted.

Red	Green	Yellow	Blue	Purple	Pink	Orange	Brown
Aka	Midori	Ki	Ao	Murasaki	Momo	Daidai	Cha
Hi	Wakaba	Lemon	Mizu	Fuji	Toki	Kaki	Chocolate
Wine	Uguisu	Karashi	Ai	Lavender	Sakura	Kaba	Coffee
	Moegi	Cream	Gunjou			Renga	
	Olive		Sora				
	Matcha						
	Kusa						

consequence of the Munsell arrangement in which the number of hue steps remains constant as saturation is reduced. If the OSA samples are, as intended, distributed uniformly in subjective color space, then it follows that the Munsell colors are not.

All things considered, the degree of agreement between the *H, V,* and *C* specifications for the 138 matching pairs is impressive. The average hue discrepancy is about 1.5 units along the 100-point circular scale. Value differences average about 0.3 unit on the 10-point scale running from black to white. The largest discrepancies are in chroma, where the average is about two steps, usually, as already noted, with the Munsell sample being of higher chroma than the OSA sample to which it is matched. The average Nickerson Index of about 10 represents quite a good match. Differences this great are often found as consequences of inadvertent manufacturing differences between samples that are nominally identical. Differences of such magnitudes can also result from changes over time ("fading"). The accuracy of computations of the Nickerson index depends upon the accuracy of MacAdam's physical measurements, as well as upon the adequacy of the Munsell renotations. The matching exercise reported here constitutes a strong validation of these methods.

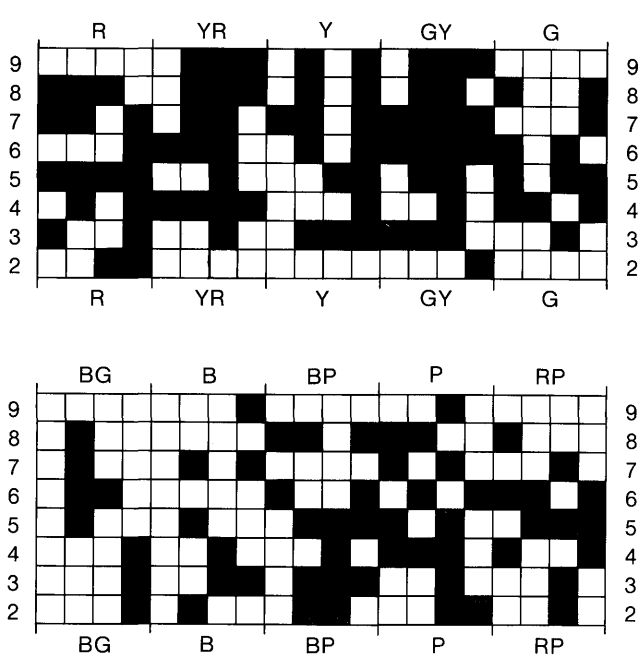

FIG. 3. Location of matching samples displayed in the hue vs. value space of Berlin and Kay. Within the *R* section, the hues are 2.5R, 5R, 7.5R, and 10R, respectively; similar designations apply to the other sections as well.

Results

Definition of Basic Terms

Table IV, which is based on the results of Uchikawa and Boynton,[5] shows the Japanese color terms that, for the purposes of the analysis to follow, will be considered as being equivalent to the English basic term that heads the list. The original list was based on the responses of ten subjects, the

TABLE V. Distribution of basic term usage for the full OSA set (OSA-F), the restricted OSA set (OSA-R, for which there are matching Munsell samples), and for testing with the restricted set of matching Munsell samples (M-R).

	Subject							
Color	MI	KM	HY	NK	YK	KH	Totals	Percent
Condition OSA-F								
Red	26	34	5	28	24	34	151	4.1
Green	186	174	209	140	220	197	1126	30.2
Yellow	66	57	53	60	68	63	367	9.8
Blue	107	85	123	124	98	84	621	16.7
Purple	79	95	115	82	94	126	591	15.9
Pink	41	48	16	50	98	46	293	7.9
Orange	62	60	58	39	70	49	338	9.1
Brown	70	24	24	38	47	38	241	6.5
Condition OSA-R								
Red	11	14	2	8	9	13	57	4.2
Green	76	66	69	43	77	73	404	29.8
Yellow	22	22	16	19	23	24	126	9.3
Blue	41	39	46	43	38	35	218	16.1
Purple	34	39	49	30	34	48	234	17.2
Pink	15	23	5	24	31	17	115	8.5
Orange	21	22	20	26	23	17	119	8.8
Brown	19	10	10	18	15	12	84	6.2
Condition M-R								
Red	8	2	3	4	3	5	25	3.6
Green	42	38	48	41	45	41	255	36.3
Yellow	8	8	3	5	9	9	42	6.0
Blue	20	19	14	16	16	14	99	14.1
Purple	20	23	27	19	25	23	137	19.5
Pink	9	6	0	5	4	3	27	3.8
Orange	11	16	5	9	16	10	67	9.5
Brown	11	8	4	10	10	8	51	7.3

results from only six of which are analyzed in this paper. Three of the terms used by the other four subjects (canary, peppermint, and violet) are not listed in Table IV because they were not employed by any of the subgroup of subjects tested here.

Frequency of Name Usage

The first section of Table V shows the number of times that each term was used, based on the full set of 418 OSA samples (excluding six grays), each viewed twice in the booth under tightly controlled conditions. This condition will be called OSA-F for short. Frequencies of color-term usage for each of the six subjects are shown, with percentages based upon group totals across rows at the right. The middle section of the table shows data for Condition OSA-R, in which the restricted set of 139 samples was selected for analysis. When based upon the restricted set of samples, the distribution of response usage across color categories seems little altered from that derived from the full set.

The bottom section of the table shows data based on the 139 Munsell samples, called Condition M–R. (There is, of course, no Condition M–F. It should be kept in mind that samples were presented twice under Condition OSA–R and only once under Condition M–R.) Now some changes do appear. For all subjects, when compared to OSA–R, the percentage use of green increases, that of yellow and pink decreases, and (with one exception) purple is used more frequently.

For OSA–F, basic terms were used 74% of the time. For OSA–R, they were employed 84% of the time. Their use in condition M–R was 81% of the time.

Centroids

Figure 4 shows the results of centroid calculations for the three conditions (also shown are data for the three juvenile subjects, to be discussed below). For the average of distances calculated separately for the eight basic chromatic color terms, the 3-dimensional distance between the centroid locations for the two most deviant subjects is 3.1 units for the OSA Full Set, 3.2 units for the OSA Restricted Set, and 3.4 units for the Munsell Restricted set. This means that appropriately located spheres of 1.5 unit radius would include almost all of the individual data points related to a given color. Centroids for the different colors are at least 6 or 7 units apart; therefore, individual centroids within color groups form tight clusters relative to the between-group separation.

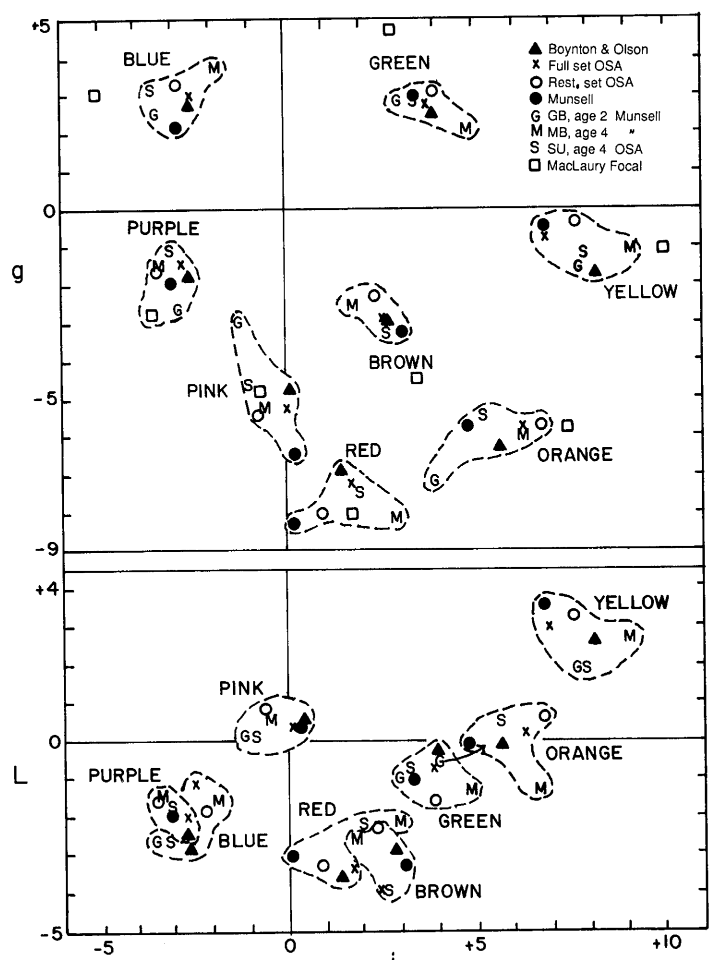

FIG. 4. Centroids for chromatic colors in the OSA space. Top: *g* vs. *j*. Bottom: *L* vs. *j*. Meaning of symbols is described in the text and is shown in the inset of the figure at the upper right.

Differences between subjects are sufficiently small relative to the noise in the data that subject rankings under one condition are poor predictors of rankings under another. (There are exceptions to this, such as HY's marked tendency to avoid pink under all three conditions, which reaches the limit of zero for Condition M–R.) For the most part, all subjects show the same trends and mean data will be discussed in the remainder of the article.

On the average, the centroids for Condition OSA–R are about 7% farther removed from the Origin ($j = g = L = 0$) than are those of condition OSA–F. This amounts to about 1 unit of OSA distance. The difference is in that direction for all colors except brown. The M–R centroids are about the same distance from the origin as the OSA–R centroids.

Discussion (Centroids)

Centroids for basic color terms calculated for the subset of Munsell samples (Condition M–R) are not very different from those based on the full set of OSA samples (Condition OSA–F), nor are the distributions of color-name usages very different between Conditions M–R and OSA–R. It can be concluded that the use of a matching subset of the Munsell samples to convert results to the OSA space, from which centroids can be calculated, has been successfully accomplished.

There is somewhat of a problem with pink. Its relative frequency of usage is about half as great with the Munsell Restricted Set when compared to the OSA Restricted Set. In going from OSA–R to M–R, the centroid for pink shifts about a unit and a half in the red direction. This result implies that purplish pinks seen under the OSA viewing conditions are now called purple; this has the converse effect of moving the purple centroid toward pink. Because of the relatively large number of purple responses, this shift is much smaller than that of pink toward red.

Focal Colors

After obtaining names for the 330 chips of the Munsell set, the adult Japanese subjects were asked to indicate the best examples of each color name that had been used (this is a standard next step of the MacLaury procedure). These focal colors are indicated by the squares in the j,g plane of Fig. 4. (To avoid clutter below, lightness values are not shown.) On average, the focal colors lie about 30% farther from the origin ($L = j = g = 0$) than the Munsell centroids, and roughly 25% farther than the OSA restricted-set centroids, confirming that subjects prefer highly saturated examples as focal examples of basic colors, rather than the center of a region to which a color term can apply.

Juvenile Data

Subject SU, age 4, daughter of Japanese author KU, was one of four subjects in the full set of ten who were tested with the OSA samples of Condition OSA–F, but who were not tested with the Munsell samples of Condition M–R. Two young subjects were tested only with the Munsell samples. These two American nephews, MB (age 4) and GB (age 2), are grandsons of author RMB. Whereas SU's data were obtained under the highly controlled conditions of our observing booth, MB and GB were tested under a variety of lighting conditions and at many different times over periods of a week or two.

Except for the use of the word *peach* on 3 occasions by MB, and *mizu* (light blue) by SU, only basic color terms were used by these three young subjects. The 4-year-olds used all of the basic color terms of their respective languages. Curiously, GB never called any of the chips *brown* or *red,* although at the age when tested he was capable of describing the colors of natural objects with these words.

The data of these three juvenile subjects are also plotted in Fig. 3. Keeping in mind that these are individual data, the agreement in centroid locations with those of the adult subjects is impressive. The exception is the orange centroid of GB, the 2-year-old who failed to use *red.* Because he identified most samples that others call red by using *orange* instead, his orange centroid is displaced in the redward direction.

Although the fact that very young subjects seem to know basic color terms and use them almost exclusively is of intrinsic interest, the purpose of presenting their data here is not to offer developmental hypotheses. Instead, we have sought to show how it becomes possible to translate data obtained only by the MacLaury method into equivalent OSA centroids, and thereby to compare data obtained by the two different methods.

Summary and Conclusions

The purpose of this study has been to compare color naming data obtained by two different methods using the same six subjects, who happen to be native Japanese. It represents a unique collaboration between investigators in separate disciplines and an attempt to coordinate the distinct metrics used by each. One method, that of MacLaury, uses 330 Munsell chips which are viewed in a natural setting under whatever illumination is available. The other method employs 424 chips of the OSA Uniform Color Scales set, which were designed to sample 3-dimensional subjective color space uniformly, under well-controlled conditions of illumination and background. After establishing that agreement was good in the gray series, the analysis dealt with the remaining eight basic chromatic colors (in English: red, green, yellow, blue, orange, purple, pink, and brown). Major emphasis was given to the procedure by which a subset of 139 samples was derived, which consists of pairs between the OSA and Munsell sets that match reasonably well, and which permit the Munsell chips to be specified in the OSA coordinate system. Although matching was done visually, an ancillary finding was that there is reasonable agreement, all things considered, between the matching results and the OSA equivalents of Munsell colors as calculated by Nickerson.

Locations of centroids, which specify the middle of the region of chips named by each color terms, were compared for the two methods of testing. Centroids based on the selected OSA samples imply somewhat more saturated colors than for the full set, consistent with the removal of less saturated samples nearer the center of the color solid. But the differences are not great. OSA full-set centroids agree rather well with those based on the restricted Munsell set despite the substantial differences in observing conditions and numbers of color samples. Consequently it becomes possible to calculate centroids for any of the large number of Mesoamerican subjects who have been tested with MacLaury's method. To show how these comparisons can be made, data for 2- and 4-year-old American subjects, tested only with the Munsell samples, were favorably compared with those of a Japanese 4-year-old subject who had been tested only with the OSA samples. Finally, it was shown that focal colors, which are those selected by subjects as the best examplars for basic color terms, are about 25% more saturated (based on OSA distance from gray) than the corresponding centroid colors.

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