COLOR VARIABILITY ASSOCIATED WITH PRINTING GCR COLOR SEPARATIONS

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Abstract: An experimental test form including normal and GCR separations that were made from the same original was printed at varying ink levels. A sampling of the press sheets were measured with a colorimeter. It was found that in most cases the use of GCR resulted in reduced image color variation, but in some cases the use of GCR actually increased image color variation. In order to reduce the intra-image color shifts that can result from the use of GCR it is recommended that high levels of GCR should be avoided.

Introduction

Within the past three or four years, a color separation technique called gray component replacement (GCR) has been introduced. One of the primary claims for GCR is that on-press process color variation will be less for GCR separations than for conventional separations.

For a given color made up of yellow, magenta, and cyan dot values, GCR involves reducing the smallest of these values together with appropriate quantities of the other two colors so that if all three reduced values were combined, they would produce a neutral gray. The removed "gray component" is replaced with a dot of black that is equal in density. A comprehensive review of the theory of GCR was published by Saleh (1984).

The less-color-variation-with-GCR claim usually centers on the role of the black printer. When printing GCR separations, a variation in black printer density will result in a shift of the lightness values of the reproduction. However, for conventional separations, a variation in one of the chromatic printers will result in hue shifts in the reproduction. Yule (1940), Jung (1984),

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Saleh (1984), and Johnson (1985), all suggest that the use of GCR will reduce color variation. Further background on the theory of GCR has been published by Keuppers (1982) and Schwartz et al (1985).

Variability in printed color is normally monitored by visual or densitometric analysis of a test image, such as a color bar. However, in practice the major area of concern in color printing is the variability of critical colors within the reproduction. The exact relationship between changes in color bar densities and the colorimetric values of the critical colors in the reproduction is not clear.

Experimental

An indication of the relationship between color bar density and colorimetric values of the reproduction may be obtained by examining a sampling of printed sheets that have been produced at a number of different inking levels. In particular, such an analysis would be valuable for determining the influence of GCR on color reproduction variability.

A test form, consisting of a RIT Process Ink Gamut (PIG) chart and two sets of color separations of the same Hell Graphics original (Jung, 1984, p. 149, 150), one with and other without GCR was prepared. The original contained the image of a Macbeth Color Checker Color Rendition Chart (McCamy et al , 1976). This chart contains 24 areas that represent the critical colors and tones that might be found in a color reproduction.

The test form was printed on coated paper using a Heidelberg MOVP press. The ink feed levels of each color were run high and low somewhat independently of each other in order to create color variation similar to that experienced in normal color printing.

Results

A sampling of press sheets were measured with a densitometer. Six of these sheets were selected for colorimetric analysis. Table I lists the densities of the sheets that were selected.

Table I
Densities of Sheets used for Analysis

Sheet No.	Yellow	Magenta	Cyan	Black
"standard"	1.12	1.38	1.53	1.59
1	1.13	1.36	1.70	1.58
2	1.10	1.54	1.64	1.28
3	1.15	1.41	1.50	1.76
4	1.09	1.31	1.42	1.14
5	1.22	1.47	1.17	1.63

A Hunter Associates, Inc. LabScan spectrocolorimeter was used for analysis of the printed sheets. The measurement conditions selected were CIE illuminant C and the CIE 1931 2 degrees standard Observer. The results were computed in terms of the CIELAB (L*, a*, b*) color space. For color difference calculations the FMC-2 formula was used.

The white paper, yellow, magenta, cyan, red, green, blue, and 4-color solids were measured on the printed PIG charts. The 24 colors in the Macbeth Color Checker chart in both the normal and the GCR reproductions were also measured. Using the press sheet marked "standard" as a color reference, the color differences of the corresponding individual color areas of the other press sheets were computed. The PIG chart L*, a*, b* values and the color differences from the "standard" sheet are presented in Table II. The average values for the white paper were: L*=93.73; a*=-0.73; and b*=3.89.

Table II
Color Gamut Variability

Yellow

L*=	87.41	a*=	-12.79	b*=	103.00			Standard
RG	0.00	YB	0.00	DL	0.00	DE	0.00	
L*=	87.60	a*=	-12.79	b*=	102.62			1
RG	- 0.11	YB	- 0.34	DL	0.49	DE	0.61	
L*=	87.50	a*=	-12.55	b*=	100.74			2
RG	- 0.04	YB	- 1.46	DL	0.26	DE	1.48	
L*=	87.19	a*=	-12.61	b*=	102.23			3
RG	0.26	YB	- 0.33	DL	- 0.54	DE	0.69	
L*=	87.11	a*=	-12.55	b*=	103.26			4
RG	0.71	YB	0.33	DL	- 0.75	DE	1.08	
L*=	87.07	a*=	-12.26	b*=	105.25			5
RG	2.06	YB	1.50	DL	- 0.82	DE	2.68	

Table II
(continued)

Magenta

L*=	47.26	a*=	73.82	b*=	- 6.31			Standard
RG	0.00	YB	0.00	DL	0.00	DE	0.00	
L*=	47.08	a*=	73.59	b*=	- 5.67			1
RG	0.55	YB	0.99	DL	- 0.31	DE	1.18	
L*=	45.48	a*=	74.64	b*=	- 2.62			2
RG	9.16	YB	6.10	DL	- 2.47	DE	11.28	
L*=	47.45	a*=	73.24	b*=	- 6.23			3
RG	- 1.64	YB	- 0.08	DL	0.20	DE	1.66	
L*=	47.10	a*=	73.33	b*=	- 5.88			4
RG	- 0.26	YB	0.58	DL	- 0.32	DE	0.71	
L*=	46.60	a*=	74.18	b*=	- 4.93			5
RG	3.66	YB	2.43	DL	- 0.91	DE	4.49	

Cyan

L*=	53.65	a*=	-26.45	b*=	-43.42			Standard
RG	0.00	YB	0.00	DL	0.00	DE	0.00	
L*=	53.24	a*=	-26.26	b*=	-43.96			1
RG	- 1.48	YB	- 0.90	DL	- 0.72	DE	1.88	
L*=	52.02	a*=	-25.19	b*=	-45.01			2
RG	- 3.90	YB	- 2.90	DL	- 2.90	DE	5.66	
L*=	53.58	a*=	-26.01	b*=	-43.85			3
RG	- 0.20	YB	- 0.56	DL	- 0.09	DE	0.60	
L*=	53.72	a*=	-26.47	b*=	-42.78			4
RG	1.38	YB	0.78	DL	0.06	DE	1.58	
L*=	54.48	a*=	-26.54	b*=	-43.09			5
RG	2.14	YB	0.97	DL	1.58	DE	2.83	

Red (Y+M)

L*=	47.15	a*=	63.04	b*=	49.12			Standard
RG	0.00	YB	0.00	DL	0.00	DE	0.00	
L*=	47.05	a*=	62.95	b*=	49.08			1
RG	0.01	YB	0.04	DL	- 0.17	DE	0.18	
L*=	45.12	a*=	65.90	b*=	43.41			2
RG	8.01	YB	- 3.53	DL	- 2.64	DE	9.14	
L*=	47.17	a*=	62.72	b*=	48.89			3
RG	- 0.73	YB	- 0.27	DL	- 0.04	DE	0.78	
L*=	47.06	a*=	62.55	b*=	50.58			4
RG	- 0.40	YB	1.39	DL	- 0.21	DE	1.46	
L*=	46.29	a*=	63.39	b*=	50.18			5
RG	2.75	YB	1.68	DL	- 1.26	DE	3.46	

Table II
(continued)

Green (Y+C)

L*=	44.39	a*=	-67.31	b*=	22.04			Standard
RG	0.00	YB	0.00	DL	0.00	DE	0.00	
L*=	43.71	a*=	-67.53	b*=	21.71			1
RG	- 1.29	YB	- 0.09	DL	- 1.30	DE	1.84	
L*=	43.23	a*=	-67.65	b*=	20.65			2
RG	- 2.73	YB	- 1.36	DL	- 2.18	DE	3.75	
L*=	44.32	a*=	-67.32	b*=	21.81			3
RG	- 0.27	YB	- 0.30	DL	- 0.13	DE	0.42	
L*=	45.40	a*=	-67.82	b*=	28.64			4
RG	5.28	YB	8.85	DL	1.76	DE	10.46	
L*=	46.52	a*=	-67.95	b*=	30.93			5
RG	8.31	YB	11.67	DL	3.98	DE	14.87	

Blue (M+C)

L*=	23.09	a*=	29.57	b*=	-48.40			Standard
RG	0.00	YB	0.00	DL	0.00	DE	0.00	
L*=	22.02	a*=	30.92	b*=	-48.42			1
RG	1.94	YB	- 1.11	DL	- 1.91	DE	2.95	
L*=	21.29	a*=	31.13	b*=	-48.71			2
RG	0.03	YB	- 2.07	DL	- 3.16	DE	3.78	
L*=	23.49	a*=	29.25	b*=	-48.43			3
RG	- 0.28	YB	0.41	DL	0.76	DE	0.91	
L*=	22.97	a*=	31.21	b*=	-47.23			4
RG	9.19	YB	0.51	DL	- 0.69	DE	9.23	
L*=	22.59	a*=	32.39	b*=	-47.71			5
RG	10.39	YB	- 0.29	DL	- 1.31	DE	10.47	

Black (Y+M+C+K)

L*=	9.13	a*=	- 3.41	b*=	0.99			Standard
RG	0.00	YB	0.00	DL	0.00	DE	0.00	
L*=	9.24	a*=	- 1.95	b*=	0.66			1
RG	4.35	YB	- 0.61	DL	0.36	DE	4.55	
L*=	9.35	a*=	- 3.05	b*=	0.89			2
RG	1.11	YB	- 0.19	DL	0.57	DE	1.30	
L*=	9.32	a*=	- 3.42	b*=	1.24			3
RG	0.50	YB	0.51	DL	0.47	DE	0.87	
L*=	10.26	a*=	- 4.18	b*=	2.78			4
RG	1.18	YB	3.72	DL	2.82	DE	4.83	
L*=	10.21	a*=	- 3.74	b*=	2.55			5
RG	2.27	YB	3.25	DL	2.72	DE	4.84	

The normal versus GCR reproductions are best evaluated by comparing their color differences. Each color in the Color Checker, for the "standard" and the other five samples were compared. The most convenient way of accomplishing this comparison was to sum the overall color difference (DE) for each sample color, for each of the press sheets, and for each reproduction. A comparison between the summed normal reproduction data and the summed GCR reproduction data will show which method of color separation is likely to produce the smallest color variation on press. Table III presents the results of the summation of color differences.

Table III
Image Color Variations for Normal and GCR separations

Macbeth Color Name	Normal*	GCR*	Difference
Bluish Green	61.54	45.72	-15.82
Orange Yellow	40.93	46.43	5.50
Cyan	106.90	38.35	-68.55
Blue Flower	48.56	55.14	6.58
Yellow Green	44.21	29.19	-15.02
Magenta	37.78	49.48	11.70
Foliage	74.93	31.26	-43.67
Purple	68.78	50.79	-17.99
Yellow	20.23	28.74	8.51
Blue Sky	73.12	46.49	-26.63
Moderate Red	52.63	45.57	- 7.06
Red	28.24	26.06	- 2.18
Light Skin	38.29	46.20	7.91
Purplish Blue	108.86	68.24	-40.62
Green	104.11	39.19	-64.92
Dark Skin	63.62	36.58	-27.04
Orange	31.09	50.73	19.64
Blue	118.14	58.84	-59.30
White	14.49	7.76	- 6.73
Neutral 8	29.42	20.56	- 8.86
Neutral 6.5	44.99	31.71	-13.28
Neutral 5	74.92	36.07	-38.55
Neutral 3.5	139.12	37.97	-101.15
Black	43.96	33.04	-10.92

*The image color variations were computed by summing the DE data from five press sheets.

The interesting observation of the "normal versus GCR" data from Table III is that some colors will exhibit less color variation with normal color separations than they will with GCR separations. One-third, or six out of eighteen chromatic colors show less variability with the normal separations. However, all of the neutral gray scale steps within the Color Checker exhibit noticeably less variation when GCR is used.

A Theory of Color Variability

A change in ink film thickness (IFT) of the individual process inks can influence individual colors within the reproduction through several mechanisms:

1. If the ink film thickness is increased, the color will become darker. Increasing IFT will also cause shifts in the hue and saturation of the individual printed ink film. For example, increasing the magenta IFT will cause the resulting printed color to be darker, redder, and less saturated.

2. If the IFT of the first-down ink is increased relative to the IFT of the second-down ink, poorer trapping will result. Likewise, if the IFT of the second-down ink is increased, relative to the IFT of the first-down ink, improved trapping will result. The effect of these changes will be to move the hue of the overprint color in either the direction of the first-down ink or the second-down ink.

3. Increasing IFT will result in increased dot gain which in turn will have the effect of darkening the tone value in question.

The influence of changes in IFT on color reproduction can be examined by comparing the Blue and Magenta colors from Table III. These colors were selected for analysis because the use of GCR benefits the Blue but serves as a detriment to the Magenta. Also, the colors are "in line" with each other on the press sheet, thus eliminating possible variations in cross-press inking as contributors to the variability of the Blue and Magenta areas.

The greatest color differences between the samples were between the "standard" sheet and sheet number five. The complete color difference data for Blue and Magenta, for the normal and GCR separations, between the "standard" and the "number 5" samples are shown in Table IV.

Table IV
Individual Color Difference Data for Blue and Magenta Areas--Standard Sheet versus Sheet No. 5

Blue, Normal Separations

RG 70.19	YB 13.97	DL 10.60	DE 72.34

Blue, GCR Separations

RG 22.92	YB 1.42	DL -5.77	DE 23.68

Magenta, Normal Separations

RG -4.85	YB -1.19	DL 4.24	DE 6.55

Magenta, GCR Separations

RG 13.43	YB 4.82	DL -5.65	DE 15.34

The halftone dot values in the Blue and Magenta areas are also required for the analysis. These values are presented in Table V.

Table V
Percentage Halftone Dot Values for Blue and Magenta Areas

	Yellow	Magenta	Cyan	Black
Blue, Normal Sep.	8	73	100	0
Blue, GCR Sep.*	1	73	100	12
Magenta, Normal Sep.	15	93	11	1
Magenta, GCR Sep.*	10	93	2	13

The data from Table V should be viewed in conjunction with those from Table I.

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*It will be noted that these are not true GCR separations. That is, all of the chromatic colors were not reduced when black was added. Nonetheless, these separations are quite suitable for purposes of color variation analysis.

The increasing of the IFT of yellow and magenta and the lowering of the cyan IFT will improve the yellow on cyan trap and the magenta on cyan trap. Also, yellow and magenta will exhibit higher dot gain with higher IFTs. The hue, saturation, and lightness of the yellow, magenta, and cyan will all change with IFT. As there is no black value printing in "normal" Blue, the change in black density will not influence this color. The net effect of these changes is to shift the "normal" Blue toward the red and yellow directions of color space and to increase its lightness.

For the GCR Blue, the previously discussed changes will also shift it toward the red and yellow directions of color space (although not as much as with the "normal" separations), and decrease its lightness. The reduced shift in red-yellow direction can be explained through the lowered influence of the yellow printer (1% yellow in the GCR Blue vs. 8% in the "normal" Blue). The decrease in lightness can be explained through the increased influence of the black printer (12% black in the GCR Blue vs. 0% black in the "normal" blue).

The above ink feed changes causes the "normal" Magenta to shift slightly in the red and yellow directions of color space and to increase in lightness. The GCR Magenta will shift more noticeably in the red and yellow directions and decrease in lightness. The increase in lightness for the "normal" Magenta can be explained by the reduced cyan density while the decline in lightness for the GCR Magenta can be explained by the increase in the black density. The reason that the GCR Magenta will shift further than the "normal" Magenta in the yellow-red direction, is that the presence of an 11% cyan in the "normal" set (compared to 2% cyan in the GCR set) must still be sufficient at reduced density to absorb some of the red-yellow shift caused by the increases in the yellow and magenta IFTs. This "braking" effect of the cyan doesn't exist for the GCR separations, therefore the red-yellow direction color shift is greater than for the "normal" separations.

Conclusions and Recommendations

The key finding of this study is that although the use of GCR separations will result in reduced color variation for most colors, in some cases the use of GCR will actually increase the color variation over that present when printing "normal" separations.

The argument made by GCR proponents that variations in density of a GCR black are less damaging to the color quality than variations in the density of one of the chromatic colors of a normal set of separations, is probably correct. However, this comparison is somewhat misleading. A more valid comparison is that between the chromatic colors of the GCR set and of the normal set.

An IFT variation in, say, the magenta of a normal separation set will result in a magenta or green (magenta's complement) cast across the entire reproduction. However, through the process known as chromatic adaptation, the eye may adapt to a slight, overall color shift.

An IFT variation in, say, the magenta of a GCR separation set will cause some colors to shift in the magenta or green directions. However, in other areas, where magenta would have been the smallest of the three chromatic inks, the colors will not change because the magenta has been replaced by black.

Therefore, the net effect of variations in chromatic inks when printing GCR separations will be selective color variation within the reproduction. Such a variation will change the relationship of colors to each other, thus upsetting the balance of the picture.

The greater the degree of GCR that is used, the greater the potential intra-image color shifts that are likely when there is variation in one or more of the chromatic color densities. Therefore, it is suggested that the amount of GCR to be used is kept to a minimum. Following this recommendation will also help to ensure that the maximum density of the reproduction is not reduced to unacceptable levels.

Changes in ink film thickness (as characterized by changes in color bar densities) can be associated with the colorimetric values of colors within the image area. However, even if this relationship is developed in advance through the use of a series of printed PIG charts or color charts, the information is not likely to be of great value. The reason for this failure is that the charts may not contain the desired color, and, even if they do, it is unlikely that sample charts exist that contain the acceptable color limits for the color in question. The practical solution to this problem is to first obtain a proof or an "OK" sheet by iterative techniques, and then to describe color variation as "perceptible", "objectionable", or "serious" (USGPO, 1979). In other words, both the acceptable level of quality and the acceptable level of variability are visually selected. The final task involves the monitoring of the critical colors to ensure that they remain within their range of acceptibility.

Given that an "OK" sheet is available, effective monitoring of color printing is possible if the press sheet carries a color bar that contains primary color solids, two-color overlap solids, resolution targets and halftone dot values. If all of these target areas match the corresponding areas on subsequent press sheets, the assumption is made that the colors in the reproduction will be consistent from sheet to sheet. In practice, the truth of this assumption may hinge on the exact nature and the number of the target areas on the color bar.

When the press is running, a side-by-side comparison of the color bars is usually the most effective method of monitoring changes in target areas. The use of a densitometer to measure target areas is useful for makeready purposes and is indispensible for conducting process control studies. Because of the time needed for measurement and computations, it is not practical to use a manual densitometer for measuring all of the target areas when the press is running at high speed. However, if "scanning densitometers" (such as the Heidelberg CPC-2 unit) that rapidly measure and evaluate a color bar, or "X-Y positioning densitometers" that can measure precise areas within the printed image are used, then it is possible to receive timely feedback data during press runs.

An alternative to monitoring color bar densities for controlling color has been suggested by Southworth (1984). He recommends that the critical image colors be measured directly through the three filters of a densitometer that has been modified to provide precise positioning of the measuring probe. An instrument having this capability was discussed by Cox (1985).

Mason (1985) has suggested using a colorimeter that has been modified to allow precise positioning of the measuring head in order to quantify the critical image colors. The advantage of the colorimeter over the densitometer is that the colorimetric data correlates well with visual estimates of color difference. The use of color difference equations in conjunction with a colorimeter makes it possible to quantify acceptable color variations in three dimensional space. This capability is of significant benefit when developing process control procedures.

The increased use of GCR color separations will not reduce the need for precise control of the color printing process. Indeed, in some cases it may be necessary to use increased color control procedures when printing GCR separations. To summarize, the best ways of monitoring color quality while the press is running would be to use either side-by-side visual comparison of color bars, three-filter densitometric or colorimetric analysis of critical colors within the image area, or high speed scanning densitometers for color bar analysis.

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Literature Cited

Cox, James R.
1985 "A New Measuring Device for Automatic Density Measurements," TAGA Proceedings 1985, pp. 487-497.

Johnson, Tony
1985 "Polychromatic Colour Removal-Evolution or Revolution?" TAGA Proceedings 1985, pp. 1-15.

Jung, Eggert
1984 "Programmed and Complementary Color Reduction," TAGA Proceedings 1984, pp. 135-150.

Kueppers, Harald
1982 "Color Atlas," Barron's Educational Series, Inc. Woodbury, N.Y., 1982.

Mason, Robert P.
1985 "Specification and Control of Process Color Images by Direct Colorimetric Measurement,"TAGA Proceedings 1985, pp. 526-545.

McCamy, C.S., Marcus, H., and Davidson, J.G.
1976 "A Color Rendition Chart," Journal of Applied Photographic Engineering, V. 11, No. 3, Summer, 1976, pp. 95-99.

Saleh, Abdel Ghany
1984 "Investigation into the Application of Achromatic Synthesis to the Printing Industry," TAGA Proceedings 1984, pp. 151-163.

Schwartz, Michael; Holub, Richard; and Gilbert, Jeffrey
1985 "Measurements of Gray Component Reduction in Neutrals and Saturated Colors," TAGA Proceedings 1985, pp. 16-27.

Southworth, Miles
1984 "Controlling Color by Varying Solid Ink Density," TAGA Proceedings 1984, pp. 286-292.

Tobais, Phillip E.
1954 "A Color Correction Process," TAGA Proceedings 1954, pp. 85-90.

Yule, J.A.C.
1940 "Theory of Subtractive Color Photography III," Journal of the Optical Society of America, Vol. 30 August 1940, pp. 322-331.