THE DEVIATION BETWEEN VISUAL AND INSTRUMENTAL CHROMA FOR PRINTED COLOR INKS

NPIRI Task Force on Color Measurement*
Key Words: Chroma, Visual, Instrumental, Prints

Abstract: The addition of low concentrations of a neutral black ink to colored inks resulted in an increase in chroma for selected prints having different film thicknesses. Visually, the prints were judged to be lower in chroma. When chroma was measured for sample pairs having nominally the same film thickness, two of nine hues showed an increase in instrumental chroma when black was added.

The increase in chroma was greatest with 0/45 and 45/0 spectrophotometer geometries, and less with sphere geometry. Unexpected chroma reversals occurred between sample pairs of the same hue made with coated and uncoated stock.

The agreement between visual and instrumental chroma was poorest with 0/45 geometry followed by 45/0 and sphere geometry. The overall visual agreement was significantly better for uncoated stock.

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INTRODUCTION

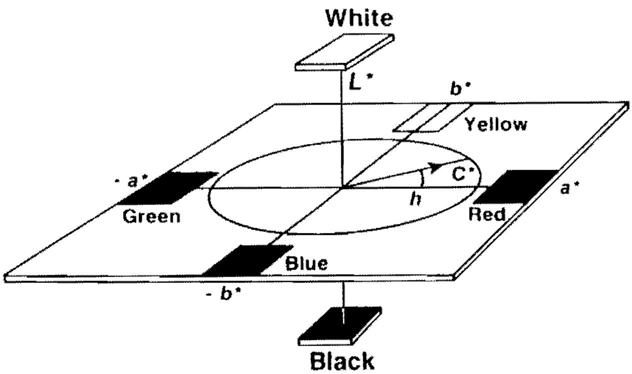
As part of a previous study(1) on visual and instrumental observations, the NPIRI Task Force on Color Measurement reported briefly on the effect of small additions of black ink on CIELAB color attributes lightness (L*), chroma (C*), and hue (h). There was good agreement between instrumental and visual observations for DL* and Dh values for paired color prints, but the correlation with chroma (DC*) was not as good. For some hues, the addition of less than one percent black ink resulted in an unexpected instrumental increase in chroma, when visually, chroma was decreased.

The research reported here has been expanded to study the effect of coated and uncoated stock (gloss effects), spectrophotometer geometry, and film thickness, for a greater number of hues.

Of the three CIELAB color attributes, chroma is the most difficult to assess and the least understood. Stanziola (2) defines chroma as "the deviation from gray. The more a color deviates from gray the more saturated it is." The textile industry uses the terms "brighter" to describe higher chroma and "duller" to describe lower chroma. The ink industry prefers the terms "cleaner" and "dirtier". Billmeyer and Saltzman (3) describe chroma as "the quality which describes the degree of difference between a color (which is itself not a white or gray, or black), and a gray of the same value or lightness." Mathematically, chroma is defined as $C^* = (a^{*2} + b^{*2})^{1/2}$ where a* is the red-green component of CIELAB color space and b* is the yellow - blue component.

FIGURE 1

CIE 1976 (L*A*B*) COLOR SPACE



Perhaps the best way to define chroma is with the use of the CIELAB color space diagram show in Figure 1. Here it is readily apparent that C* starts at the vertical white-black (gray) axis, where the chroma is zero, and increases in value as it moves horizontally away from the gray axis. In comparing print samples, it would appear that the terms "more gray" and "less gray" are fundamental and more appropriate than "dirtier", "cleaner" or "brighter", "duller", etc.

PROCEDURE

Three sets of print samples were evaluated. The first set ("Laboratory Prints") were laboratory prints made on coated stock with nine hues. When matching color, it is common practice to add low concentrations of black ink to tone the inks. Consequently, a neutral black ink in concentrations of 0.25, 0.50, 1.0, and 1.5 percent was added to each of the hues. Using exactly the same amount of ink, 10 prints were made with each hue, and with each concentration of black. In all, 450 printed samples were made.

The second set of samples consisted of Pantone chips made with coated and uncoated stock selected from the Pantone Formula Guide 1000. Ten sets were selected (coated and uncoated) on the basis of black additions and chroma. The samples are referred to as "Pantone Chips" in the paper.

The third set of samples consisted of two color wheels made with coated and uncoated Pantone chips. A gray-yellow chip (Pantone 103) was placed in the center of the wheel with 14 saturated colors arranged around the circumference of the wheel.

Measurements of all samples were made with X-Rite 938 (0/45), Gretag SPM50 (45/0), and Datacolor CS-3 (sphere) spectrophotometers. Unless otherwise noted, all readings were reported for D50 illuminant/ 2° observer.

EXPERIMENTAL RESULTS

As research on this project progressed, it became apparent that instrumental readings of chroma were quite sensitive to ink film thickness. However, in the real world of commercial color matching, the film thickness of samples that are provided are not usually known. Figures 2 through 10 show the extent to which instrumental chroma can deviate from visual ratings for sample pairs having different film thicknesses. Base colors were selected from the eighth, ninth, or tenth prints (lower chroma, lower film thickness) and prints made with black added were selected from the first, second, or third prints (higher film thickness, higher chroma). The extent to which chroma decreases with film thickness is shown in Figure 11.

Chroma values are shown for nine hues to which 0.5 and 1.0 percent of a neutral black ink was added. 0.5 percent and 1.0 percent additions were selected to represent what normally happens in practice. For some hues, the deviations (increase in chroma) with the addition of black were greater when the 0.25 percent black was added.

FIGURE 2

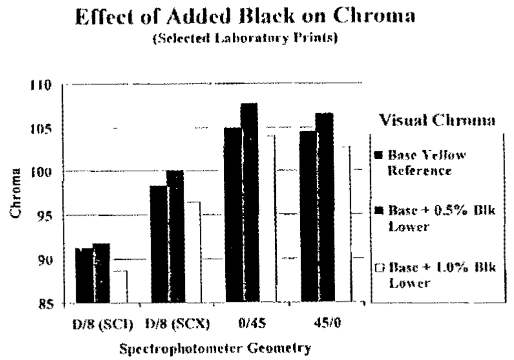


Figure 2 shows the effect of the addition of 0.5 and 1.0 percent black ink on the chroma of a yellow ink for four spectrophotometer geometries. Note that for each geometry, the addition of 0.5 percent black increased chroma. As noted previously, the addition of 0.25 percent black resulted in an even greater increase in chroma. The increase in chroma was greatest with 0/45 geometry and least with sphere geometry, specular included (SCI). The greater increase in chroma with 0/45 geometry was consistent for all hues and all samples tested. When the concentration of black ink was increased to 1.0 percent, chroma decreased in all cases, the expected behavior. The visual rating (consensus) was that the addition of black ink decreased chroma. Visually, a panel made up of seven Task Force members rated both samples to which black was added lower in chroma.

FIGURE 3

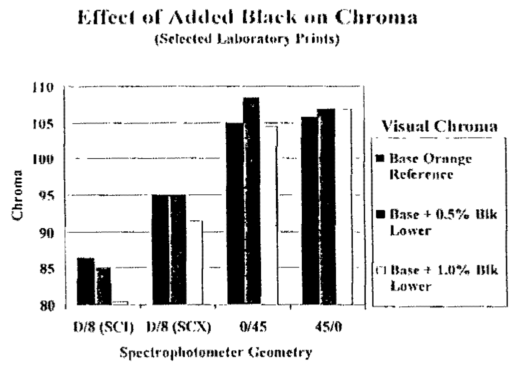
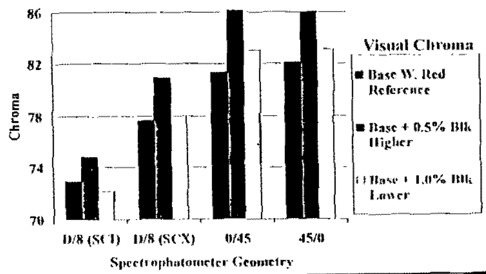


Figure 3 shows that with orange ink, the addition of 0.5 percent black decreased instrumental chroma for the sphere geometries (SCI and SCX), but increased chroma with 0/45 and 45/0. With 1.0 percent black added chroma decreased for the sphere geometries and decreased slightly for 0/45 geometry. The visual rating was lower chroma for both samples.

Figure 4 shows the large increase in chroma for the hue warm red with the addition of 0.5 percent black. Again, the increase is greatest for 0/45 geometry, and less with 45/0, sphere (SCX) and Sphere (SCI), in that order. The addition of as much as 1.0 percent black also resulted in an increase in chroma for 0/45, 45/0, and SCX geometries. SCI was the only geometry to show a decrease with 1.0 percent black added. With warm red, the panel rated the sample with 0.5 percent black higher in chroma, and with 1.0 percent black, lower in chroma.

FIGURE 4

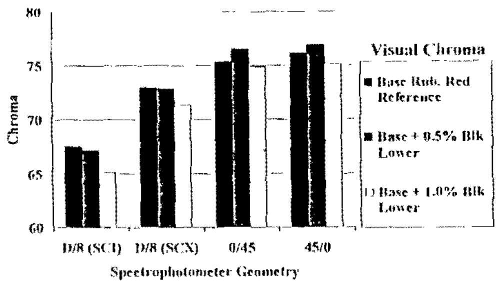
Effect of Added Black on Chroma
(Selected Laboratory Prints)



A slight increase in chroma was observed with prints made with rubine red pigment (Figure 5) for 0/45 and 45/0 geometries. Chroma decreased slightly for SCX and SCI geometries. When 1.0 percent black was added, chroma decreased for each geometry. Visually, the panel rated both samples lower in chroma.

FIGURE 5

Effect of Added Black on Chroma
(Selected Laboratory Prints)



Prints made with rhodamine pigmented ink (Figure 6) show a slight increase in chroma with 0.5 percent added black for 0/45, 45/0, and SCX geometries, and a slight decrease for SCI geometry. The chroma with 1.0 percent black added was about the same as the base ink except for SCI geometry, which was lower, as expected. With 0.5 percent black the visual rating was higher chroma, and with 1.0 percent the rating was lower.

FIGURE 6

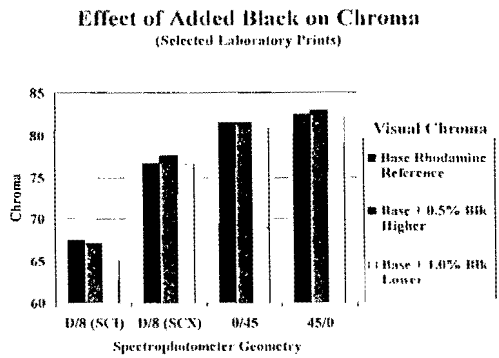
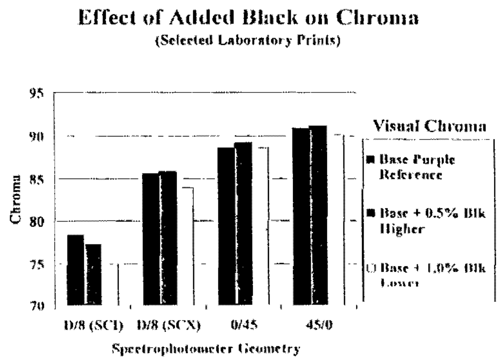


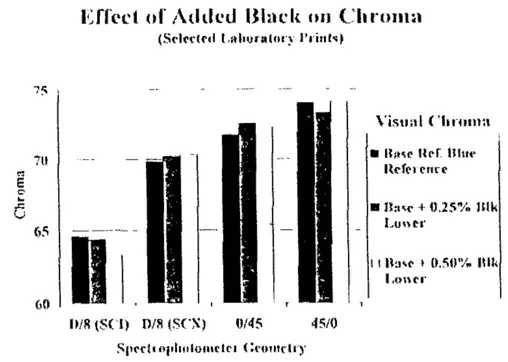
Figure 7 shows that for purple prints, chroma increased slightly with 0.5 percent black added for 0/45, 45/0, and SCX geometries, but decreased when 1.0 percent black was added. The chroma with SCI geometry decreased with the addition of 0.5 and 1.0 percent black. The panel rated the 0.5 percent black sample higher, and the 1.0 percent black lower in chroma.

FIGURE 7



In Figure 8 (reflex blue prints), 0.25 percent added black increased chroma for 0/45 and SCX geometries, decreased chroma (slightly), for 45/0 geometry, and was the same for SCI geometry. With 0.5 percent black added, chroma increased slightly for 0/45, 45/0, and SCX geometries, and decreased for SCI geometry. Both samples were rated lower in chroma visually.

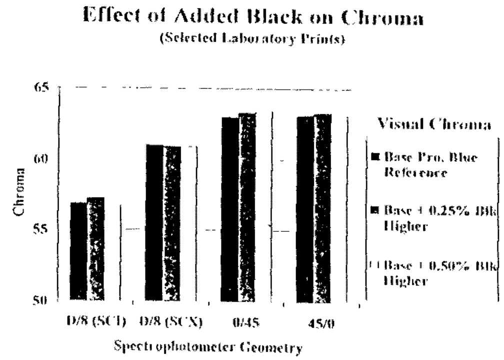
FIGURE 8

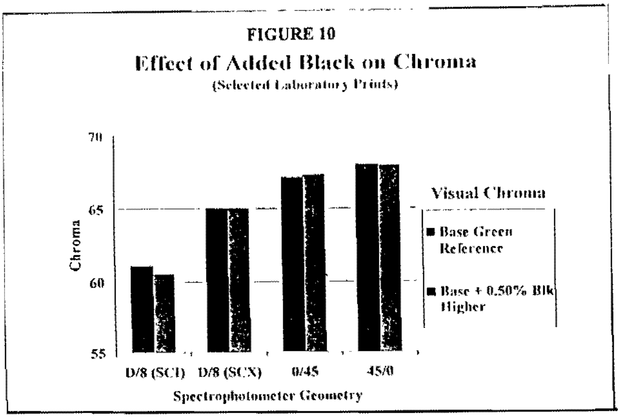


Chroma data for process blue prints are shown in Figure 9. With 0.25 percent black added, chroma increased slightly for 0/45, 45/0, and SCI geometries, and was the same for SCX geometry. When 0.5 percent black was added, 0/45 geometry was slightly higher, and 45/0, SCX and SCI were about the same as the base ink. Both samples were rated visually higher in chroma.

Chroma data for green prints with 0.5 percent black added are shown in Figure 10. For green, chroma decreased slightly for 45/0, SCX, and SCI geometries, and increased slightly with 0/45 geometry. The panel rated the sample to which 0.5 percent black was added higher in chroma.

FIGURE 9





To summarize the results of Figures 2-10, when prints having different film thicknesses were compared (which is not uncommon in the world of color matching), a disparity can exist between instrumental and visual chroma assessments. The degree of disparity is dependent upon spectrophotmeter geometry and the hue being evaluated.

Figure 11 shows the sensitivity of chroma to ink film thickness for nine base hues, and with 0.5 percent black added. The laboratory press (Gallus) used to make the prints does not permit the direct measure of ink film thickness. However, exactly the same amount of ink was applied to the rollers for each hue. Ten consecutive prints were made without re-inking so that less ink was available for each successive print. The chroma data reported in Figure 11 are for the first print (maximum chroma) minus the tenth print (minimum chroma). The chroma for orange, warm red, and yellow hues decreased significantly for the base colors, where the decrease was minimal for purple, reflex blue, and process blue. The addition of black decreased chroma sensitivity to film thickness for five of the nine hues.

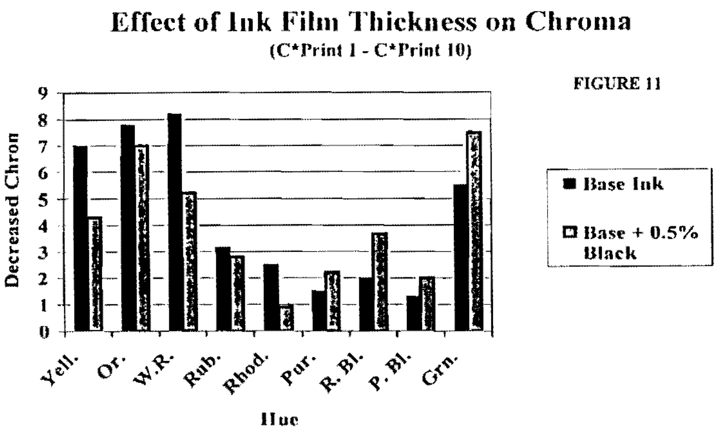


Figure 12 shows the disparity that can exist between instrumental and visual chroma. Chroma data are shown for Pantone chip 1767 C, a base pink and 1767 C to which 0.1 percent black has been added (707C). 0/45 chroma increased from 29.0 to 33.8, a 17 percent increase, when 0.1 percent black was added. Increases are also shown for 45/0, SCX, and SCI geometries in decreasing order.

FIGURE 12

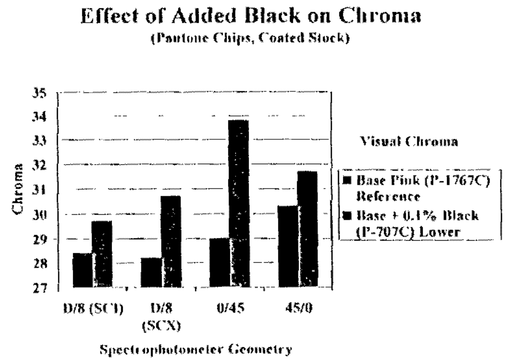


Figure 13 shows the same Pantone colors measured at the same film thicknesses, with a Gretag SPM-50 (45/0) spectrophotometer. At the same film thickness, the chroma measurements exhibit "normal" behavior in that chroma decreases with the addition of as little as 0.1 percent black ink.

The results shown in Figure 12 are probably due to the Pantone 707 chip having a thicker ink film than the Pantone 1767 chip. However, as shown in Table 1 essentially the same results were obtained at three laboratories that used different Pantone color books. This would indicate that Pantone 707 is printed (consistently) heavier to match a color standard.

FIGURE 13

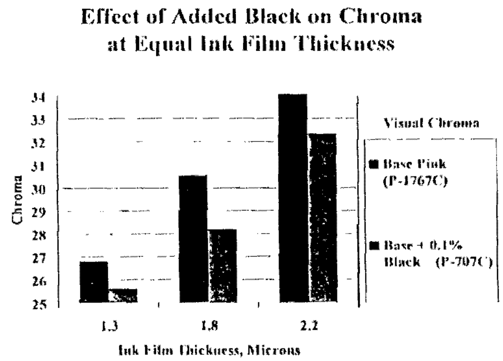
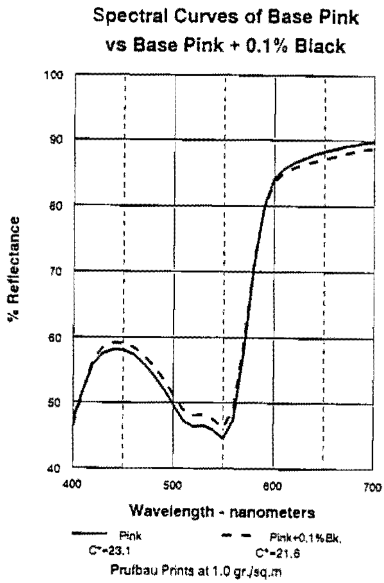


TABLE 1
CHROMA EVALUATION - THREE LABORATORIES

	Laboratory		
	A	B	C
P - 1767C (Base)	29.0	29.4	24.2
P - 707C (Base +0.1% Bl.)	33.8	33.5	29.0
Increase in Chroma	4.8	4.1	4.8

To study this further, reflectance curves were made using a Datacolor CS-3 sphere spectrophotmeter, specular included for prints having the same (1.0 gr./sq.m or 1 micron)film thickness using a Prufbau press. The curves, plotted in Figure 14, show an unexplained anomally in that at low frequencies the reflectance of Pantone 707 which contains 0.1 percent black was higher than the reflectance for the base ink (Pantone 1767). At high frequencies, the reflectance for 707 was lower, which is the expected result when black is added to a base ink. Collectively, the Task Force has over 200 years experience in analyzing reflectance curves. Not one member ever recalls an instance when reflectance increased with the addition of black when samples are compared at the same film thickness.

FIGURE 14



Figures 15 and 16 show chroma as a function of concentration of black ink for nine hues at (nominally) the same film thickness. The same ten prints that were used selectively and reported in Figures 2 to 10 are shown except that the average chroma for the ten prints is reported. Since exactly the same amount of ink was used it is reasonable to conclude that the ink film thickness was approximately the same for each hue. However, the possibility does exist that ink transfer properties are slightly different for each hue even though the inks were made to the same basic formulation.

When the average of 10 prints is used to report chroma, most of the hues exhibited expected behavior in that chroma decreased with the addition of black ink. However, there were some exceptions. Warm red (Figure 15) showed an increase in chroma at a concentration of 0.25 percent black and a slight increase at 0.5 percent black. Also rubine (Figure 15) demonstrated no decrease, and rhodamine (Figure 16) had a slight increase in chroma with 0.25 percent black added.

FIGURE 15

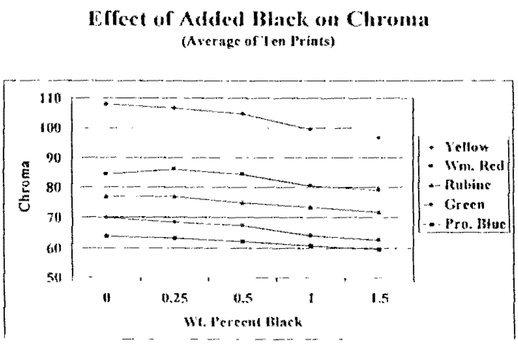


FIGURE 16

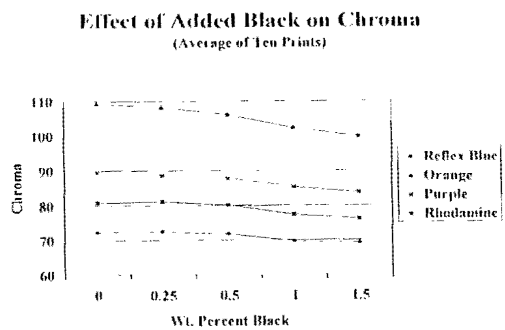
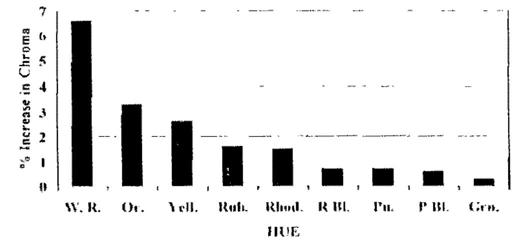


Figure 17 shows the effect of hue on increased chroma when 0.5 percent black is added for selected prints. Warm red (red lake C pigment) had the greatest increase in chroma followed by orange, yellow, rubine, and rhodamine. Reflex blue, purple, process blue, and green showed a slight increase in chroma.

FIGURE 17

Effect of Hue on Increased Chroma with 0.5% Black Added
(Selected Prints)



The effect of spectrophotometer geometry on increase in chroma for 10 hues with 0.5 percent black added is shown in Figure 18. The average percent increase was greatest for 0/45 geometry followed by 45/0, SCX, and SCI geometries.

FIGURE 18

Effect of Spectrophotometer Geometry on Increase in Chroma
(10 Hues, 0.5% Black Added)

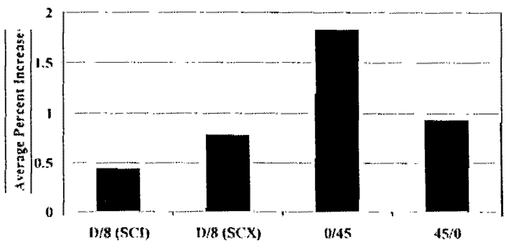


Figure 19 shows the difference in chroma for prints made with coated and uncoated stock. For each hue, chroma increased with increased gloss, (coated stock) as expected. The increase in chroma was greatest for blue 072, and least for yellow.

FIGURE 19

Chroma of Prints Made With Coated and Uncoated Stock (0/45 Geometry)

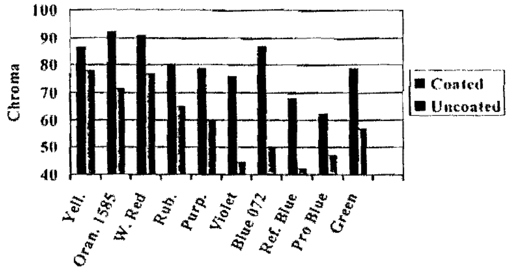
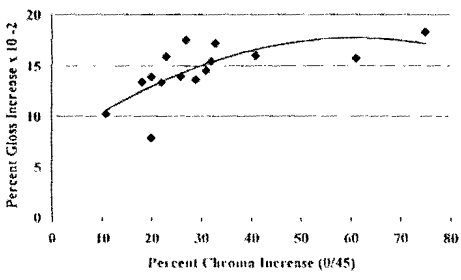


Figure 20 correlates increased chroma with increased gloss when comparing uncoated stock (low gloss, low chroma) with coated stock (higher gloss, higher chroma). Although there is scatter in the data, the trend line shows that at a 10 to 15 percent increase in gloss, chroma increases gradually, but between 15 and 20 percent, the increase in chroma is rapid.

FIGURE 20

Correlation Between Increased Chroma and Increased Gloss (Coated / Uncoated Stock)



Figures 21 and 22 are academic in the sense that comparisons would not normally be made between sample pairs having different hues. Nevertheless, the results are interesting in that the gray-yellow reference sample (Pantone 103) was visually lower in chroma than the eight fully saturated colors shown, but measures (0/45) higher in chroma for coated stock, and lower in chroma for uncoated stock. The chroma reversals between coated and uncoated stock are unexplained at this time, but perhaps are due to gloss effects.

FIGURE 21

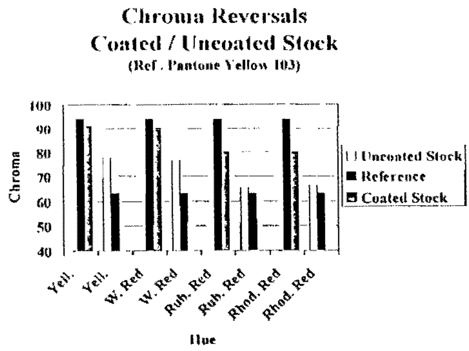


FIGURE 22

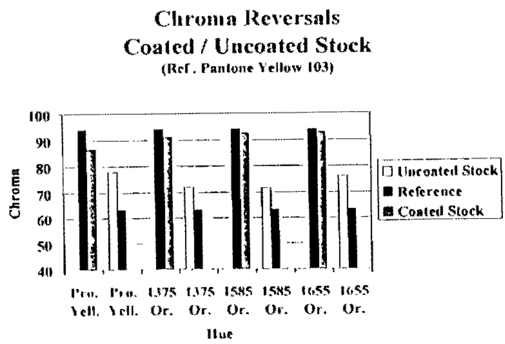


Figure 23 summarizes the chroma reversals for 14 hues that occur between coated and uncoated stock with four spectrophotmeter geometries. The greatest number of reversals (8 of 14 or 57 percent) occurred with 0/45 geometry, followed by 45/0 (43 percent), D8/SCX, (36 percent), and D8/SCI, (21 percent).

FIGURE 23

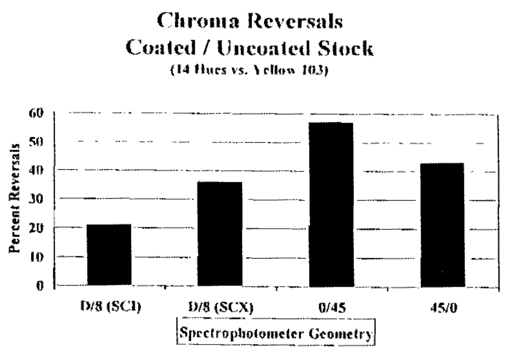
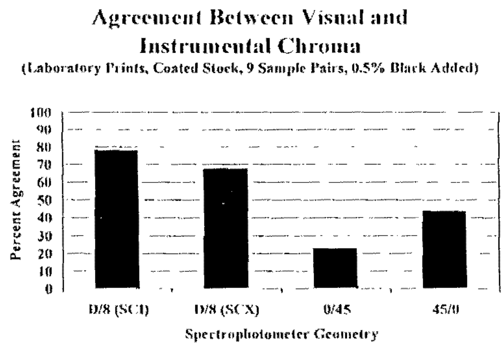


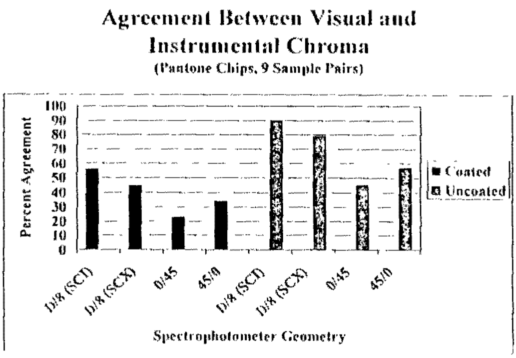
Figure 24 presents the agreement between visual and instrumental chroma for the nine laboratory prints on coated stock. Sample pair comparisons were made with the same hue with and without 0.5 percent black added. The poorest agreement was with 0/45 geometry, followed by 45/0, D8/SCX, and D8/SCI.

FIGURE 24



The visual/instrumental agreement for 9 pairs of coated and uncoated Pantone chips is shown in Figure 25. The sample pairs represent the same hue with and without black added. There is much better agreement between visual and instrumental with the low gloss, uncoated stock chips. Also, the same pattern regarding spectrophotometer geometry repeats itself, that is, 0/45 was the poorest followed by 45/0, D8/SCX, and D8/SCI.

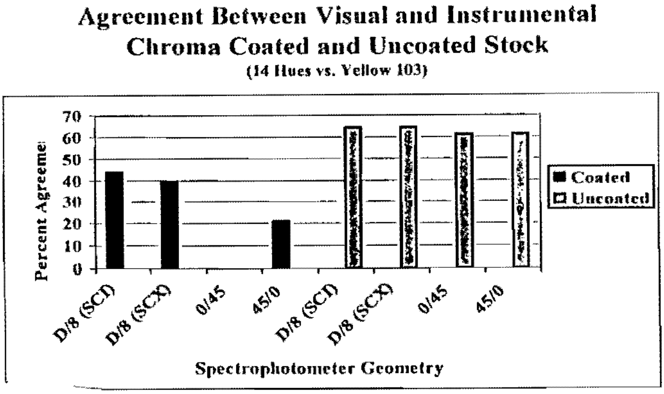
FIGURE 25



The agreement between visual and instrumental ratings of the same sample pairs was much better for the samples printed on uncoated stock (low gloss) than coated stock (higher gloss). Gloss definitely exacerbates the disparity between visual and instrumental chromas, particularly for 0/45 and 45/0 geometries.

Figure 26 shows the visual/instrumental agreement for fourteen saturated hues (coated and uncoated stock) paired with a gray-yellow (Pantone 103). Again, the agreement was much better for uncoated stock, but the differences between spectrophotometer geometries with these dissimilar sample pairs was insignificant. There was a marked difference for prints made with coated stock where 0/45 was by far the poorest followed by the usual order of 45/0, D8/SCX, and D8/SCI.

FIGURE 26



DISCUSSION OF RESULTS

At the outset of this project, it became apparent that Task Force members had different viewpoints on what chroma is, and how it should be assessed visually. It is, without a doubt, the least understood of the three color attributes and the most difficult to assess. There was disagreement as to whether or not the chroma for different hues could be compared because of different lightness values. The confusion stems from a misconception of the fundamental definition of chroma which states that the chroma of a sample must be compared to a gray of the same lightness. The definition does not exclude a comparison of different hues with different lightness values. If it did, it would exclude quantitative comparisons that are made using the Munsell color tree.

Regarding the spectrophotometric measurements, the addition of a neutral black ink (i.e. nominally zero chroma) to a colored ink should always result in lower instrumental chroma. However, this was not always the case, particularly if ink film thickness is not kept the same. In the real world of color matching, one is not always sure of matching print samples at the same film thickness. If spectrophotometric data alone are used, there could be some instances where the instrument says to decrease chroma, when visually that is not the case. With the exception of three hues: warm red, rhodamine, and rubine, chroma always decreased with the addition of black at the same film thickness. The reason for this warrants further investigation.

The reversals in instrumental chroma that occurred between coated and uncoated stock of the same hue also warrants further investigation. This aberration was greatest for directional geometries, and least for sphere geometry, specular included.

CONCLUSIONS

- The addition of low concentrations of black ink to colored inks increases instrumental chroma when paired prints having different film thickness are selected.
- When paired prints having the same film thickness are compared, only two of nine hues had an increase in instrumental chroma.
- Instrumental chroma decreases with decreased ink film thickness. The magnitude of the decrease is related to hue.
- The increase in chroma for selected prints with black added is also related to hue.
- The increase in chroma for inks to which black was added was greatest with 0/45 geometry, followed by 45/0, D8/SCX, and D8/SCI, in that order.
- The chroma of prints made with coated stock was always greater than prints made with uncoated stock.
- Unexpected chroma reversals occurred between coated and uncoated sample pairs of the same hue. Reversals were greatest for 0/45 and 45/0 geometries.
- The agreement between visual ratings and instrumental chroma was poorest with 0/45 geometry followed by 45/0, D8/SCX, and D8/SCI. The overall agreement was better for uncoated stock than coated stock.

ACKNOWLEDGMENT

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