COLOR MEASUREMENTS OF PRINTS USING MULTI-SITE SPECTROPHOTOMETRIC INSTRUMENTATION

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ABSTRACT: The use of spectrophotometers to evaluate and monitor ink strength and print quality is rapidly growing. Although instrument manufacturers have established specifications for inter-instrument agreement in a controlled environment, minimal data exists on inter-instrument agreement correlation at multiple sites. In an effort to evaluate multi-site differences, printed test targets were measured at a primary site with a portable 0/45 degree spectrophotometer and then sent to numerous locations for measurements with similar instruments. Statistical evaluation of multi-site differences indicate that significant differences in colorimetric measurements can exist between identical instrumentation. Suspected sources of measurement error (calibration, temperature/humidity, inter-instrument repeatability, fade, individual user repeatability and multiple user repeatability) were studied and ranked. The importance of taking inter-instrument variations into consideration when establishing color tolerances for multiple instruments is also discussed.

INTRODUCTION

The extensive use of spectrophotometers to measure color and/or color differences has resulted in increased comparisons of colorimetric data between multiple sites. Since it is known that all the instruments do not give the same absolute numbers, the question arises as to the comparability of colorimetric data obtained from similar instrumentation at multiple sites.

While our total study included both directional and sphere geometry instruments, the information in this paper focuses on the variability seen with the same model 0°/45° portable spectrophotometers. Data from instruments using different geometries should not be compared and instruments from different manufacturers may give additional variability.

Since the graphics arts industry typically measures printed samples, and multiple test targets were needed to complete the study, we designed and printed a special test target. The target consisted of process color and black patches printed to SWOP "Lo" densities on an opaque 100# non-fluorescing index stock. (An opaque stock was used to eliminate the need for a black or white backing.) Special grid marks were printed next to the targets to assist with instrument alignment, when repeat measurements were taken on the same spot.

Before establishing reasonable color tolerances, the instrument variability must be known. Thus, by obtaining information regarding the possible sources of measurement error, steps can then be taken to minimize the variability and improve color communication between multiple sites.

INSTRUMENT COMPARISON PROCEDURE

Forty-three sites participated in this study utilizing 50 portable spectrophotometers of the same model. One of these spectrophotometers, located at the primary site, was selected as the referee instrument. L*, a*, and b* values were calculated from the spectrophotometric measurements taken on the four target patches (black, cyan, magenta and yellow). This process was repeated to obtain measurement data on 49 separate test targets.

One test target for each instrument was sent to each of the 43 locations for the same colorimetric measurements with off-site instrumentation. Measurement data and test targets were then returned to the primary site where difference (delta) values between the primary instrument and each off-site instrument were determined. Selected targets were also re-read with the referee instrument (no significant differences were apparent). The following are the measurement conditions used to complete this study.

Geometry	0°/45°
Illuminant	D5000
Observer	10°
Measurement Area	4mm
Color Space	CIELAB

COLORIMETRIC DATA ANALYSIS AND RESULTS

Data from the various locations were input into a spreadsheet to calculate the colorimetric differences and to complete the analysis. High/low values, means and standard deviations were determined from the DE*, DL*, Da* and Db* data for each color. Table 1 below summarizes the results obtained from the 49 portable spectrophotometers.

Table 1

Statistical Results From 49 Portable Spectrophotometers

	DE*				DL*				Da*				Db*			
	High	Low	Mean	Std. Dev.	High	Low	Mean	Std. Dev.	High	Low	Mean	Std. Dev.	High	Low	Mean	Std. Dev.
Black	1.01	0.07	0.56	0.24	0.62	-0.62	-0.04	0.26	0.73	-0.76	0.11	0.26	0.95	-0.76	0.25	0.35
Cyan	0.99	0.09	0.35	0.17	0.26	-0.34	-0.01	0.12	0.79	-0.19	0.13	0.19	0.33	-0.69	-0.22	0.16
Magenta	1.47	0.17	0.87	0.33	0.74	-0.72	0.26	0.23	0.81	-0.16	0.26	0.25	1.22	0.01	0.71	0.33
Yellow	1.23	0.13	0.52	0.26	0.51	-0.43	0.12	0.2	0.6	-0.81	-0.04	0.24	1.01	-0.42	0.29	0.39

To show the individual differences between instrument measurements, Da*-Db* plots were completed for each color. These are shown in Figures 1-4. Ellipses fitted to the data points vary in size and shape. The variation seen with the cyan, excluding two outlying data points, (Figure 2) is significantly smaller in comparison to the other colors.

Figure 1
Black CIE Da*-Db*

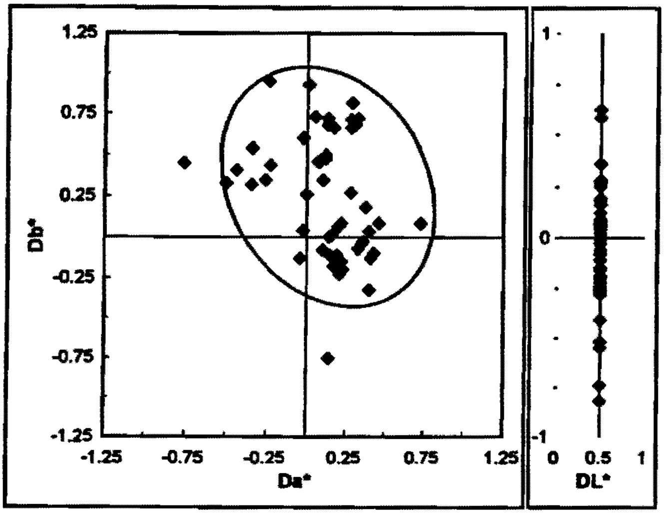


Figure 2
Cyan CIE Da*-Db*

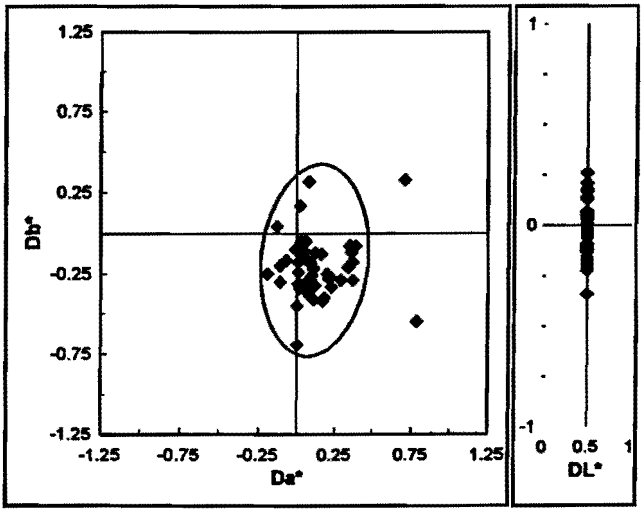


Figure 3
Magenta CIE Da*-Db*

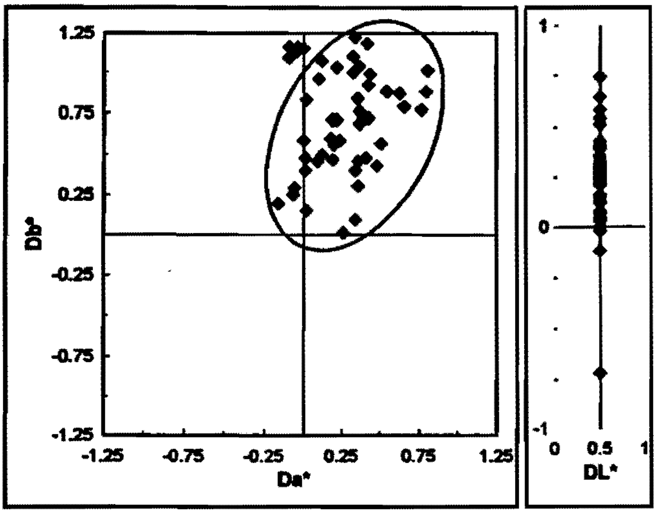
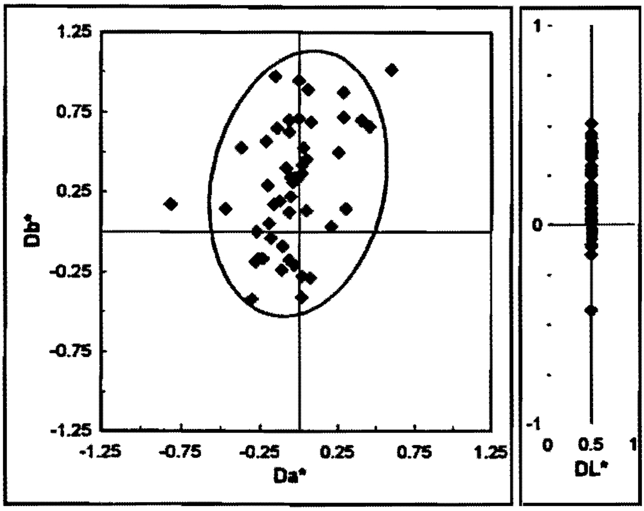


Figure 4
Yellow CIE Da*-Db*



The histograms presented in Figures 5-8 show the frequency distribution for the yellow DE*, DL*, Da* and Db* values. These histograms show no similarities in distribution to those obtained for the black, cyan and magenta.

Figure 5

DE* Yellow - Frequency Distribution

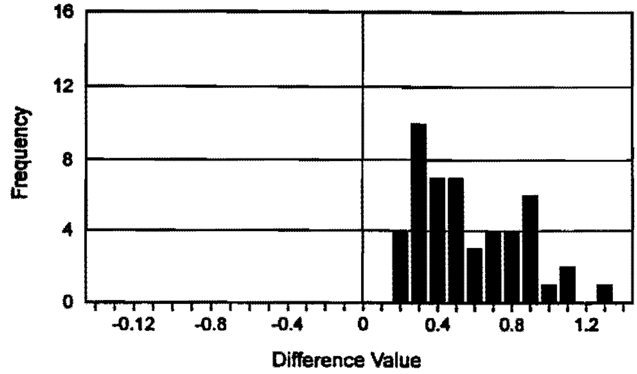


Figure 6

DL* Yellow - Frequency Distribution

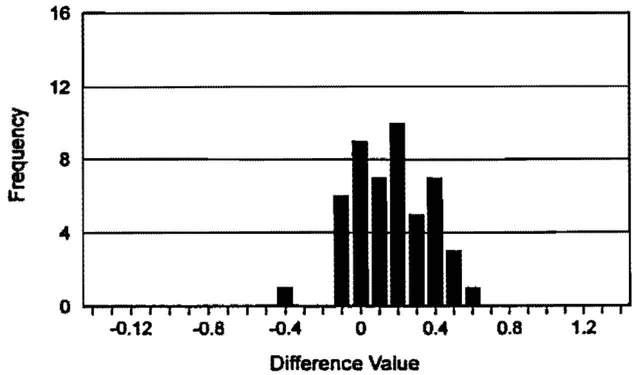


Figure 7

Da* Yellow - Frequency Distribution

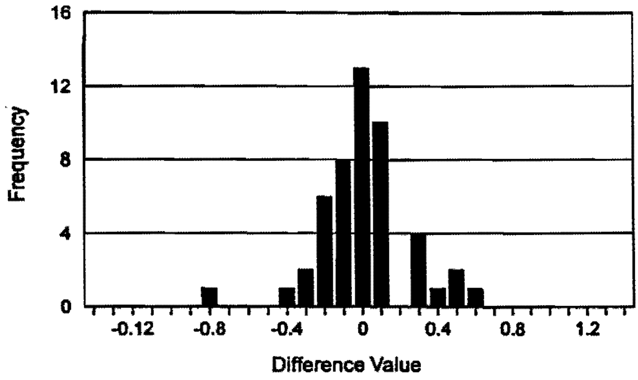
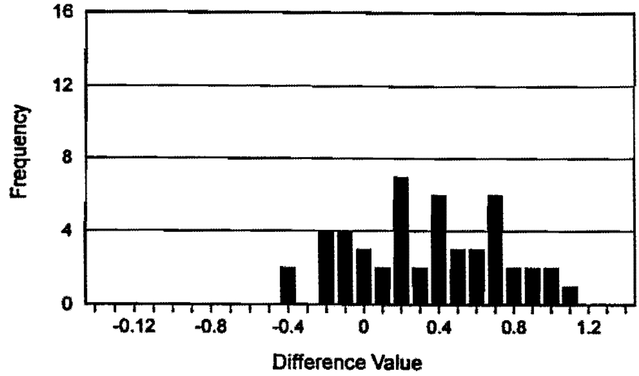


Figure 8

Db* Yellow - Frequency Distribution



SOURCES OF MEASUREMENT ERROR

Suspected sources of measurement error were identified, quantified, and the significance of each measurement error was compared to colorimetric data from the multi-site study. The standard deviations for each factor are contained in Table 2. Figures 9-12 display rankings of each factor based on the data in Table 2.

Table 2

Standard Deviations of Possible Factors Influencing Measurements

	Black			Cyan			Magenta			Yellow		
Factor[1]	L*	a*	b*	L*	a*	b*	L*	a*	b*	L*	a*	b*
Repeat A[2]	0.04	0.02	0.02	0.03	0.03	0.03	0.01	0.02	0.04	0.01	0.01	0.07
Repeat B[3]	0.04	--	--	0.02	0.03	0.02	0.04	0.02	0.02	0.01	0.01	0.08
Instrument	0.07	0.21	0.36	0.15	0.36	0.46	0.13	0.24	0.4	0.11	0.41	0.12
Temp/Hum	0.04	0.02	0.02	0.03	0.09	0.14	0.28	0.27	0.27	0.08	0.29	0.08
Fade A[4]	0.02	0.01	0.06	0.02	0.04	0.2	0.03	0.03	0.05	0.04	0.04	0.26
Fade B[5]	0.09	0.01	0.11	--	0.05	0.07	0.03	0.04	0.06	0.08	0.04	0.22
Calibration[6]	0.03	--	--	--	--	--	0.02	0.01	--	0.04	0.01	0.01
Total	0.33	0.27	0.57	0.25	0.59	0.93	0.54	0.64	0.84	0.37	0.82	0.81
Measured[7] Std. Dev.	0.28	0.28	0.38	0.12	0.19	0.18	0.23	0.25	0.33	0.20	0.24	0.39

1) All standard deviations were corrected to account for the variations found with an individual user. 2) Repeatability of an individual user. 3) Repeatability of multiple users. 4) Test target enclosed in a white envelope for an 8 week period. 5) Test target exposed to fluorescent lamps for an 8 week period. 6) Recalibration between readings. 7) Standard deviation for differences between 49 instruments

Figure 9
Black
Ranking of Possible Factors Influencing measurements

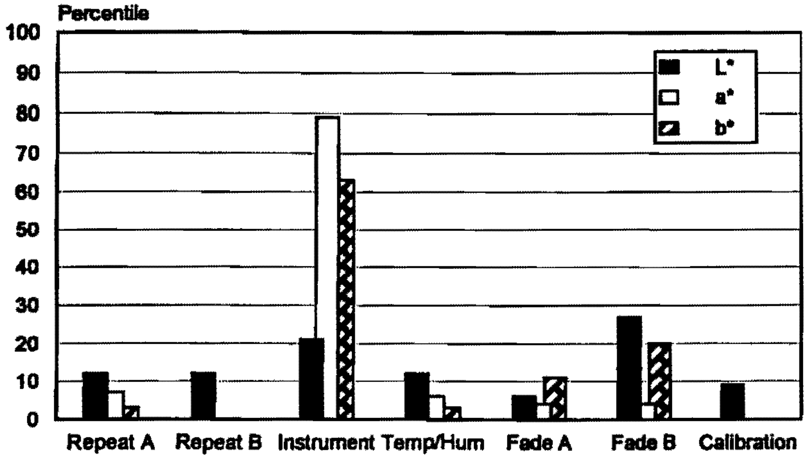


Figure 10
Cyan
Ranking of Possible Factors Influencing measurements

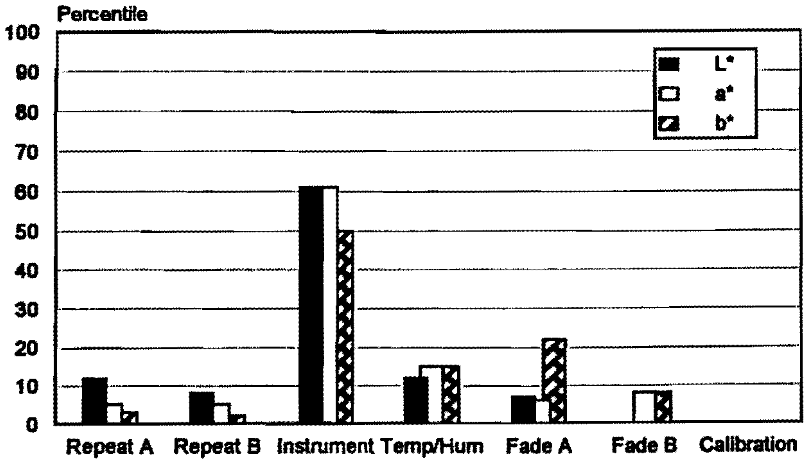


Figure 11

Magenta

Ranking of Possible Factors Influencing measurements

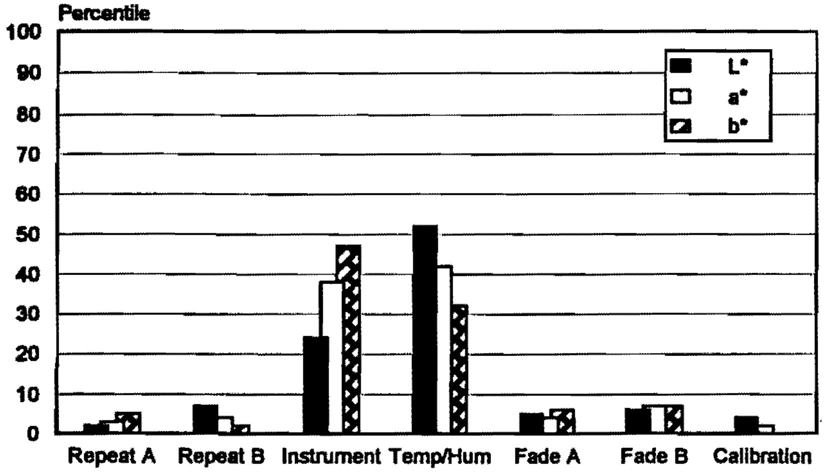
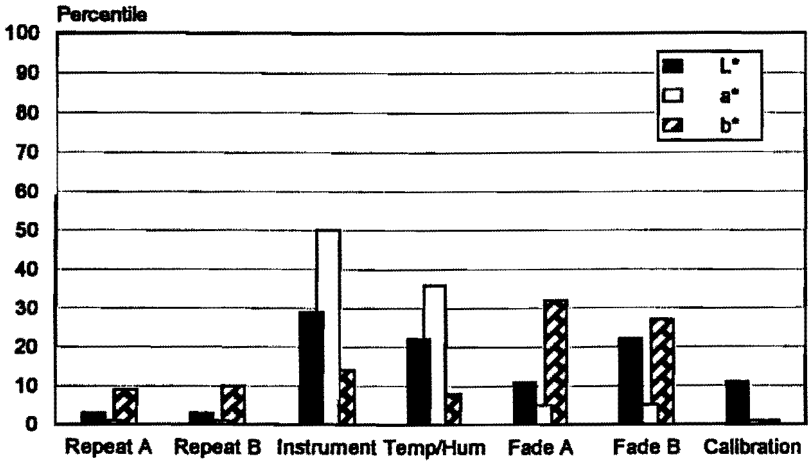


Figure 12

Yellow

Ranking of Possible Factors Influencing measurements



To determine the error associated with individual repeatability (Repeat A), one individual took six separate measurements on the same four color patches using the same instrument. Multiple user repeatability (Repeat B) was determined by having six different individuals take measurements on the same four color patches with the same instrument. The standard deviation was calculated for each colorimetric value. The results in Table 2 and in Figures 9-12 show that the errors associated with individual and multiple user repeatability are relatively small in comparison to the other sources of error.

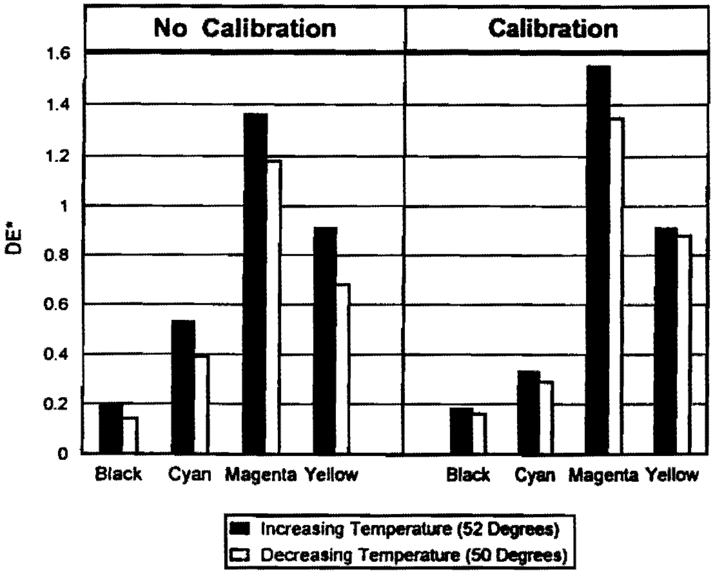
Inter-instrument error was evaluated by having one individual take measurements on the same target using seven similar instruments. The resulting standard deviations in Table 2 indicate that multiple instrumentation tends to provide the largest amount of error as expected. The second greatest error was observed with temperature and humidity.

To determine the effect of temperature and humidity error on the colorimetric measurements, a test target was measured by one individual under seven different temperature and humidity conditions. Temperatures ranged from 62°F to 94°F while humidity varied between 20% and 92%. These results (Tables 2 and Figures 9-12) indicate that while temperature and humidity errors were a primary factor with the magenta, they were secondary with the black, cyan and yellow.

To further evaluate the effect of temperature and humidity, measurements were made on the same target by an individual under two significantly different temperature and humidity conditions; 57°F with 37% humidity and 108°F with 0% humidity. Under the second temperature condition for both increasing and decreasing tests, measurements were made before and then again after instrument calibration. The resulting DE* values for each of the colors, Figure 13, show that differences between increasing and decreasing temperatures are minimal for the black, cyan and yellow if the instrument is re-calibrated. The larger differences seen with magenta can be attributed to the changes occurring within the magenta sample (it is well known that rubine magenta inks fluctuate in shade with temperature and humidity changes). We have also observed with the magenta that reducing the temperature range from 52° to 27°F results in a 50% reduction in error with the DE* value.

Figure 13

Effect of Increasing and Decreasing Temperatures
With No Calibration and With Calibration



Test target fade was examined by placing test targets inside a white envelope (Fade A) and leaving test targets out under normal fluorescent lighting (Fade B). Targets were read by one individual using the same instrument each week for an eight week period. These results indicate that significant differences were apparent with yellow lightness and chroma values on the targets that were exposed to fluorescent lighting. As a part of this study, we also examined the colorimetric changes of the stock over the same test period and observed significant changes as much as 1.27 in the +b* direction with the exposed target. These results could account for some of the differences seen with the yellow test targets.

To evaluate errors associated with instrument calibration, one individual measured the same target 12 times calibrating between each set of measurements. The error found with calibration was relatively insignificant. However, a preliminary study found that slightly more error may occur if the manufacturer's recommendation for cleaning the plaque with isopropyl alcohol is not followed.

DISCUSSION OF RESULTS

DE* values for similar instrumentation varied significantly, from 0.07 to 1.47, among the 49 instruments. The combined average DE* value for the black and color patches was 0.57. This combined average was approximately three times higher than the manufacturer's DE* inter-instrument specification of 0.20 which is based on the average DE* of 12 BCRA tiles. It was expected that the manufacturer's specification would be significantly smaller since the BCRA tiles are a more permanent medium measured in a highly controlled environment. The NPIRI Task Force on Color Measurement (1993 and 1994) showed that larger variations were obtained with ink on paper in comparison to the BCRA tiles and that the extent of the differences varied with each of the colors. In reviewing these results and those supplied by the manufacturer, it is apparent that the differences in DE* values are color dependent and employing combined DE* averages may be misleading.

Several of the larger DE* values tended to be associated with the magenta patch measurements. An evaluation of the error sources showed that the magenta targets were most sensitive to changes in temperature and humidity. Although temperatures and humidities were not recorded at each location, it is possible that different temperature and humidity conditions did effect the magenta and other color patches, which resulted in higher magenta DE* values. To reduce differences associated with temperature and humidity it would be optimum to measure samples in a temperature and humidity controlled environment. Alternately, if temperature and humidity cannot be controlled, the error can be reduced by recalibrating an instrument as a function of environmental changes and following manufacturer's recommendations for cleaning calibration plaques prior to calibration.

Comparing the differences in CIE Da*- Db* plots reveal that the least variation is associated with cyan and the greatest with yellow which tended to move in the +b* direction. Some of the variations with the yellow could be attributed to the substrate yellowing as previously described.

Within the measurement errors studied, the largest contributor to instrument variation was inter-instrument differences. Temperature and humidity had the next most significant affect on the samples and instrument variation, while instrument calibration had much less affect on variation. Individual and multiple user errors were both insignificant, however, it was observed that with multiple users the error increased to almost twice that of an individual. To determine the absolute difference between individual and multiple user repeatability, more data is required. In reviewing the results of possible error sources in relation to the results from the multi-site instrumentation, it was encouraging to see that the sum of the standard deviations for the sources of measurement error were generally significantly larger than those associated with the multi-site instrumentation, thus suggesting that we have considered the largest sources of error.

To establish tolerances for multi-site instrumentation, more data may be necessary. The data obtained thus far for the 49 instruments indicates that at least 92% of all data for each colorimetric value falls within a tolerance of ± 2 standard deviations. In addition, the variability in the colorimetric data suggests that tolerances need to be set for each colorimetric value rather than using a single DE* tolerance for each color. Due to the inherent variability with a large number of instruments, in addition to having multi-site tolerances, it may be useful to establish individual tolerances between certain instruments. To reduce the variability even further, the standard should be measured with each instrument and those values used for color difference evaluations.

The information from this study indicates that some instrument variability may be eliminated by controlling the temperature and humidity conditions in which measurements are made as well as the time between printing and measurements. While both individual and multiple user repeatability were relatively insignificant in comparison to other errors, it was gratifying to see that the error associated with multiple users was only twice that of a single user. In addition, it was also determined that unnecessary repeated instrument calibration may lead to increased measurement errors. Understanding the various aspects of instrument variability as well as taking steps to minimize them, is important in establishing inter-instrument tolerances for improving color communication between multiple sites.

CONCLUSIONS

1. The range in DE* values for measurements with 49 identical instruments varied from 0.07 to 1.47 with an average DE* value of 0.57.

2. Individual measurement error studies show that the largest portion of variation between instrumentation may be attributed to inter-instrument differences.

3. Temperature and humidity conditions have a significant affect on the samples and instrument variation. The greatest differences were most apparent with the magenta target. Recalibrating the instrumentation helps eliminate this error.

4. Multiple users' error was generally twice that of individual user error. Both multiple and individual user errors were insignificant in comparison to other errors evaluated in this study.

5. Unnecessary repeated instrument calibration may increase measurement errors.

6. There is a need to educate users about factors that can cause measurement variability. Minimize suspected sources of error before establishing tolerances.

7. The variability between the colorimetric data suggests that tolerances need to be set for each colorimetric value rather than using single DE* tolerance for each color.

8. In communicating colorimetric data, it may be useful to establish individual tolerances for each instrument in addition to having multi-site tolerances.

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