The Effect of OBA in Paper and Illumination Level on Perceptibility of Printed Colors

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Abstract

A research was conducted to study the perceptibility of color difference of color pairs, caused by OBA differences in paper substrates, and its relationship with quantitative measurement metrics. Based on the psychometric experiments conducted, the results show the utilization of the visual difference index (VDI), from 0 (no difference) to 3 (noticeable difference), to rate 27 color pairs with each pair prepared by the same colorants but different OBA amount in the substrates. The findings indicate that (a) printed colors are affected by the presence of OBA from no difference to noticeable difference, (b) ΔE_{00} has a stronger linear correlation with visual color difference than ΔE^*_{ab} does, (c) there is no significant association between illumination levels and visual color difference. This research introduces the metric, OBA, per ISO 15397 (2013), as the CIE-b* difference in color pairs under M1 and M2 conditions. It also defines ΔOBA as the OBA difference between any color pairs, including substrates. The results show that there is linear correlation (1) between visual difference and ΔE_{00} which describes the color difference, and (2) between visual difference and ΔOBA which describes the criticalness of M1 lighting to realize the color match.

When OBA loaded papers are used in printing, Three primary issues arise: (1) color of the paper, namely CIE-b* value, is out of specifications, (2) printed colors and their conformance, e.g., solids and grays, are influenced by the paper color, and (3) there is a color mismatch between contract color proofs and the final prints.

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Introduction

Color aims for commercial printing are traditionally based on paper substrates without optical brightening agents (OBAs). Today, OBAs are widely used in printing papers. Print buyers often prefer brighter papers and the use of OBAs provide brighter stocks at lower cost and with less environmental impact than bleaching methods which were traditionally utilized to provide sheets with increased brightness.

Literature Review

This section discusses the fundamental of OBA, how we visualize color difference, and how we measure color difference through literature review.

OBA fundamental

Papers with OBA require ultraviolet radiation of illuminant wavelengths below 400 nm for their excitation; the energy then re-emits in the blue region. This brings the peak reflectance value at about 457 nm. The colorimetric effect is a shift of CIE-b* value, up to ten units. The visual effect is a shift from yellowish white to bluish white.

Chung and Tian (2011) show that the effects of OBA impact light ink-covered areas the most. Human eye senses the OBA-induced difference on light-covered ink areas easily. In other words, the use of OBA substrate can introduce a color shift both visually and colorimetrically. There is a need, therefore, to evaluate the visual difference of printed color that is induced by OBA.

Visualizing color difference

Habekost (2013) compared several color difference equations in corresponding with perceived color differences. Both groups of trained and untrained observers, in regard to judging color differences, were asked to rank color differences of test colors. The observers viewed the color patches in a viewing booth with 5000K lighting. Visual differences between the standard and the sample patch were ranked as: match (5), slightly different (4), different (3), more different (2) and very different (1). The ranking scheme was then turned visual responses into a scale from 1 to 5.

To study the effect of differences in substrate white point on the acceptability of colour matches, London College of Communication conducted a psychometric experiment, utilizing a six-point scale to rate the size of color difference between reference and sample. The visual scaling is based on perceptibility and acceptability thresholds where 1-2 indicating not perceptible or only barely perceptible, 3-4 indicating acceptable and 5-6 indicating unacceptable (Green, Baah, Pointer & Sun, 2012).

Measuring color differences

CIELAB color difference is the Euclidean distance between the two different L*a*b* values representing the two different specimens in the CIELAB color space. ΔE^*_{ab}, developed in 1976, is a popular color difference formula. Because of the ease of computation, ΔE^*_{ab} has been widely used in the graphic arts industry.

Presently, ΔE_{00} is recommended by ISO 13655 (2009) for the calculation of small color differences. One primary goal of the ΔE_{00} formula is to correct for the non-uniformity of the CIELAB color space for small color differences.

Objectives

The objectives of this research are three-fold: (1) to rank visual color difference between prints with and without the presence of OBA; (2) to study the relationship between visual color difference and color difference metrics, namely, ΔE^*_{ab} and ΔE_{00}; and (3) to investigate whether visual color differences depend on illumination levels.

Methodology

The following procedures were used to carry out the psychometric experiment: (1) color samples were prepared and measured, (2) observers were screened, and (3) visual ranking experiments were conducted, and (4) data analyses and hypothesis testing were performed:

1. Preparing and measuring color samples

A total of 27 pairs of printed color patches, derived from the IT8.7/4 Target (1,617 color patches in all), were prepared to sample the color space in lightness, hue, and chroma, using the same colorants printed on the paper with OBA (Invercote G) and the same paper without OBA (Invercote T).

Each of the 27 sample pairs, in the dimension of 3.5” x 7”, was prepared using Adobe InDesign. The digital file was exported in PDF/X-1a: 2001 standard and output to the Kodak Approval imaging system. The “donors” were then transferred through a laminator on the two paper substrates (Invercote T and Invercote G).

Each sample pair was placed in edge contact and mounted on a matte gray cardboard. As shown in Figure 1, the 50% cyan tint on Invercote T (non-OBA substrate) is mounted on the left side and the same 50% cyan tint on Invercote G (OBA substrate) is mounted on the right side.

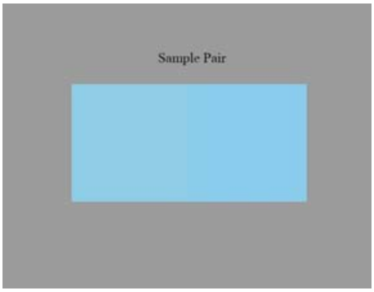


Figure 1. *An example of a sample pair*

CIELAB values of all samples were measured in M1 and M2 measurement modes using an X-Rite i1 Pro2 spectrophotometer. ΔE^*_{ab} and ΔE_{00} between color pairs were computed according to ISO 13655.

2. Screening observers

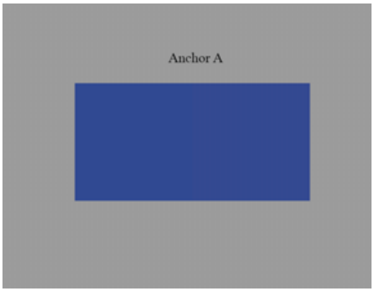
The Farnsworth-Munsell 100 Hue Test was utilized to screen observers. Recommended procedures from the manufacturer were adhered to, including conducting the study in a standardized viewing condition. Caps were randomized using the cover of the case. Observers were asked to arrange the caps according to the two fixed colors at the end of a case by moving the caps by hand without touching the color. Although no time limit was given, a typical screening took 10-12 minutes to conduct in a quiet surrounding.

A total of 35 students and staff from the College of Imaging Arts and Sciences at RIT volunteered to participate in the study. Based on an unacceptable performance in the Farnsworth-Munsell 100 Hue Test, only one individual was eliminated from the observer panel.

3. Conducting visual scaling experiments

The viewing condition was the GTI viewing cabinet capable of adjusting the illuminant intensity to ISO 3664 P1 and P2 conditions.

Two anchor pairs were present in the psychometric experiment. Anchor Pair A is the reference for ‘no difference’ because it is the assembly of two identical dark color patches. Anchor Pair B is the reference for ‘noticeable difference’ because it is the assembly of the two paper substrates, Invercote T and Invercote G (Figure 2).



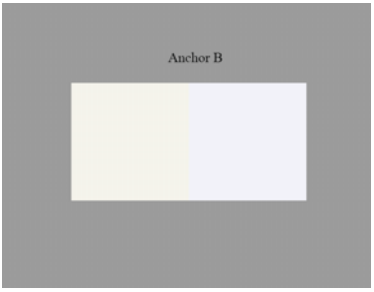


Figure 2. *Anchor pair A (no difference) and B (noticeable difference)*

During the visual ranking experiment, a random sample pair was shown with the two anchor pairs presented under P1 and P2 illumination conditions. Each observer was asked to assign a visual difference index (VDI), to the sample pair. A 4-point scale was used: '0' indicating no difference; '1' indicating just noticeable difference (JND), '2' indicating more than JND, and '3' indicating noticeable difference.

4. Performing data analyses

Individual scores on visual ranking were tabulated and averaged in terms of VDI. The linear relationship between visual difference index (VDI) and color difference metrics was analyzed. Even though the VDI is an interval scale with a range from 0 to 3, the present study treats it as a continuous scale after all VDI responses were averaged.

To study whether visual color difference depends on illumination levels, sample pairs with high densities or high TAC were examined under P1 and P2 viewing conditions. Two-way tables and the Chi-square test were employed to test if there is association between illumination levels and visual color difference.

Results

The research findings can be grouped in the following sub-topics: (1) frequency distribution of sample pairs, (2) relationship between visual color difference (VDI) and measured color difference (ΔE^*_{ab} and ΔE_{00}), (3) association between visual color difference and illumination intensity.

1. Frequency distribution of sample pairs

A total of 34 observers participated in the psychometric experiment. Out of 27 color pairs, 5 of the averages fell in the category of 'no difference'; 4 of averages fell in the category of 'JND'; 4 of averages fell in the category of 'More than JND'; and the rest (14) fell in the category of 'noticeable difference' (Figure 3).

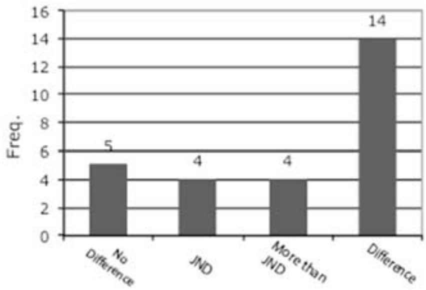
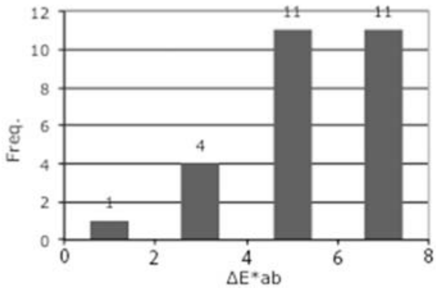


__Figure 3.__ Histogram based on visual ranking experiment

Figure 4 (left) shows the ΔE*ab frequency distribution with four intervals, from 0-2, 2-4, 4-6, and 6-8. Figure 4 (right) shows the ΔE00 frequency distribution using the same intervals.



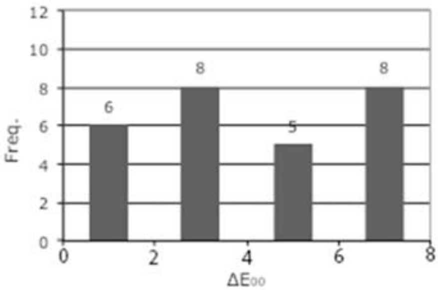


*__Figure 4.__ Histogram based on ΔE*ab (left) and ΔE00 (right)*

Figure 4 indicates that (a) the range of measured color differences is the same (8) for ΔE*ab and ΔE00; (b) the distribution of these color differences are different between the two metrics.

Transforming visual ranking (from no difference to noticeable difference) into visual difference index (from 0 to 3) was instrumental in quantifying visual sensation of small color differences. In hindsight, it might have been better to further differentiate the 'noticeable difference' category if we used a 5-point scale with '5' being 'very different' or 'not acceptable.'

2. Relationship between measured and visual color difference

By replacing the visual ranking difference into numerical values (from 0 to 3), we can study the linear correlation between the VDI (or visual difference index) and measured color difference. Figure 5 shows the linear relationship between the ΔE*ab, ΔE00 metric (y-axis) and the visual difference index (x-axis).

The coefficient of determination, denoted R2, indicates how well data points fit a straight line. In this experiment, ΔE_{00} color difference metric results in a higher correlation coefficient (R2 = 0.79), than that of ΔE^*_{ab} metric (R2 = 0.46). This indicates that that ΔE_{00} has a stronger linear correlation with visual color difference than ΔE^*_{ab}.

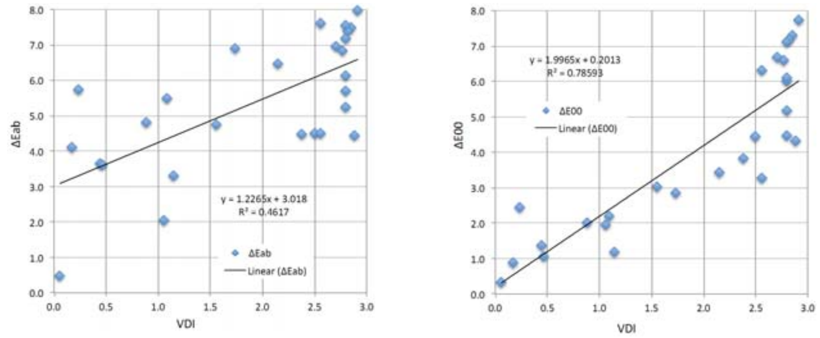


Figure 5. *Correlation between ΔE*ab vs. VDI (left) and ΔE00 vs. VDI (right)*

By examining the two graphs in Figure 5 visually, we can see that ΔE_{00} values are more clustered (less spread) in the 'No Difference', 'JND', and 'More than JND' regions than ΔE^*_{ab} values. This visual examination supports the linear correlation analysis that ΔE_{00} metric correlates with small visual color differences better than ΔE^*_{ab} will.

3. Relationship between perceived color difference and illumination intensity

To investigate whether visual color difference of color pair depends on illumination levels, three dark-tone (or high TAC) pairs, Pairs 12, 23, and 27, were selected. Two-way tables and the Chi-square test were used to test if there is significant association between illumination levels and color difference indices.

Using Pair 12 (C0M0Y0K80), a 80% black tint, as an example, the Chi-square test statistics is 3.215, the p-value (Chi-square >= 3.215, df=2) is 0.2 > 0.05, indicating that there is no significant association between illumination levels and color difference indices.

The results of Chi-square test for Pair 23 (C100M100Y0K0), a cyan/magenta overprint solid, and Pair 27 (C40M27Y27K100), a four-color overprint, were the same as Pair 12. This research concludes that there is no significant association between illumination levels and visual color difference.

Although there is no significant association between illumination levels and color difference indices, Figure 6 shows that observers tend to see more color differences for Pair 12 under P1 than under P2 conditions.

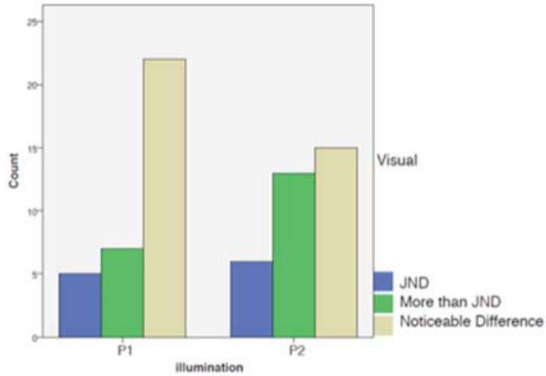


Figure 6. *Bar chart under two illumination levels for Pair 12*

Further Research

The paper industry has been working on quantifying the OBA effect in paper. ISO/FDIS 15397 (2013) describes two metrics, ΔB and OBA, to quantify OBA effect in paper.

1. ΔB metric

The first metric is based on the brightness value of the paper under D65 illumination (ΔB). The brightness method, as detailed in clause 5.12 of ISO/FDIS 15397, states that the OBA effect is the difference of D65/10-degree Brightness measurement performed with UV and with a UV-cut filter. Furthermore, fluorescence can be classified into four levels: faint (0-3), low (4-7), moderate (8-13), and high (>14).

There are two issues with the brightness method: (1) the graphic art industry uses D50/2-degree as the primary illuminant/observer combination, not D65/10-degree, to measure color, and (2) fluorescence of a single substrate, influenced by the OBA amount, should not be classified into visual terms because the visual sensation of paper 'white' is relative.

2. OBA metric

The second metric (OBA), also described in clause 5.12 of ISO/FDIS 15397, is the difference of the CIE-b* values between M1 and M2 measurement conditions in D50 illumination (Eq. 1).

$$OBA = b^*_{M2} - b^*_{M1} \qquad \text{Eq. (1)}$$

The quantity, b*M1, is the b* value of the paper including pulp and OBA. The quantity, b*M2, is the b* value of the paper including pulp, but excluding OBA. Thus, OBA indicates the degree of fluorescence that can be expected in graphic arts viewing and measurements.

This research defines the metric, ΔOBA, as the OBA difference between any color pairs with and without OBA in substrates, S1 and S2 (Eq. 2).

$$\Delta\ OBA = OBA_{S1} - OBA_{S2} \qquad \text{Eq. (2)}$$

A key interest in this research is whether VDI (derived from the psychometric experiment) and ΔOBA (the difference between two OBA amounts of color pairs with and without OBA in their substrates) relates to each other. Figure 7 illustrates that there is a good linear correlation between VDI and ΔOBA with a R-square value of 0.62.

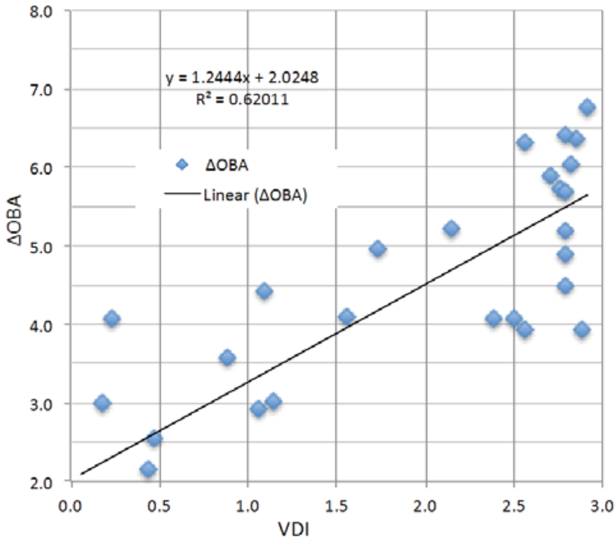


Figure 7. *Linear correlation between VDI and ΔOBA*

In color proofing, it is the OBA difference between the two substrates (ΔOBA), not the OBA amount of the substrate that influences their visual difference. We can categorize the degree of fluorescence into four levels: no difference to JND (0-3 ΔOBA), more than JND (3-6 ΔOBA), noticeable difference (6-9 ΔOBA), and very different (>10 ΔOBA).

In color proofing, the larger the ΔOBA is, the more critical is the viewing illumination and the color management task in the M1 color-managed workflow.

Conclusions

This research only studied the color difference of color pairs with OBA and without OBA in their substrates. We conclude that (a) printed colors are affected by the presence of OBA from no difference to noticeable difference, (b) ΔE_{00} has a more linear correlation with visual color difference (VDI) than ΔE^*_{ab} does, (c) there is no significant association between illumination levels and visual color difference. In addition, there is a good correlation between VDI and ΔOBA.

While OBA amount, as defined in Eq. (1) is material dependent, both ΔE_{00} and ΔOBA are performance criteria in proof-to-print color match. While ΔE_{00} describes color matching, ΔOBA describes the criticalness of M1 lighting to realize the color match.

Acknowledgments

We wish to express their appreciation to Iggesund Paperboard company for donating Invercote T and Invercote G paper, GTI for providing the ISO 3664 (2009) compliant viewing booth, and X-Rite for providing ISO 13655 M1 spectrophotometer. They also want to recognize RIT School of Media Sciences for providing the academic environment that enables us to excel and learn.

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