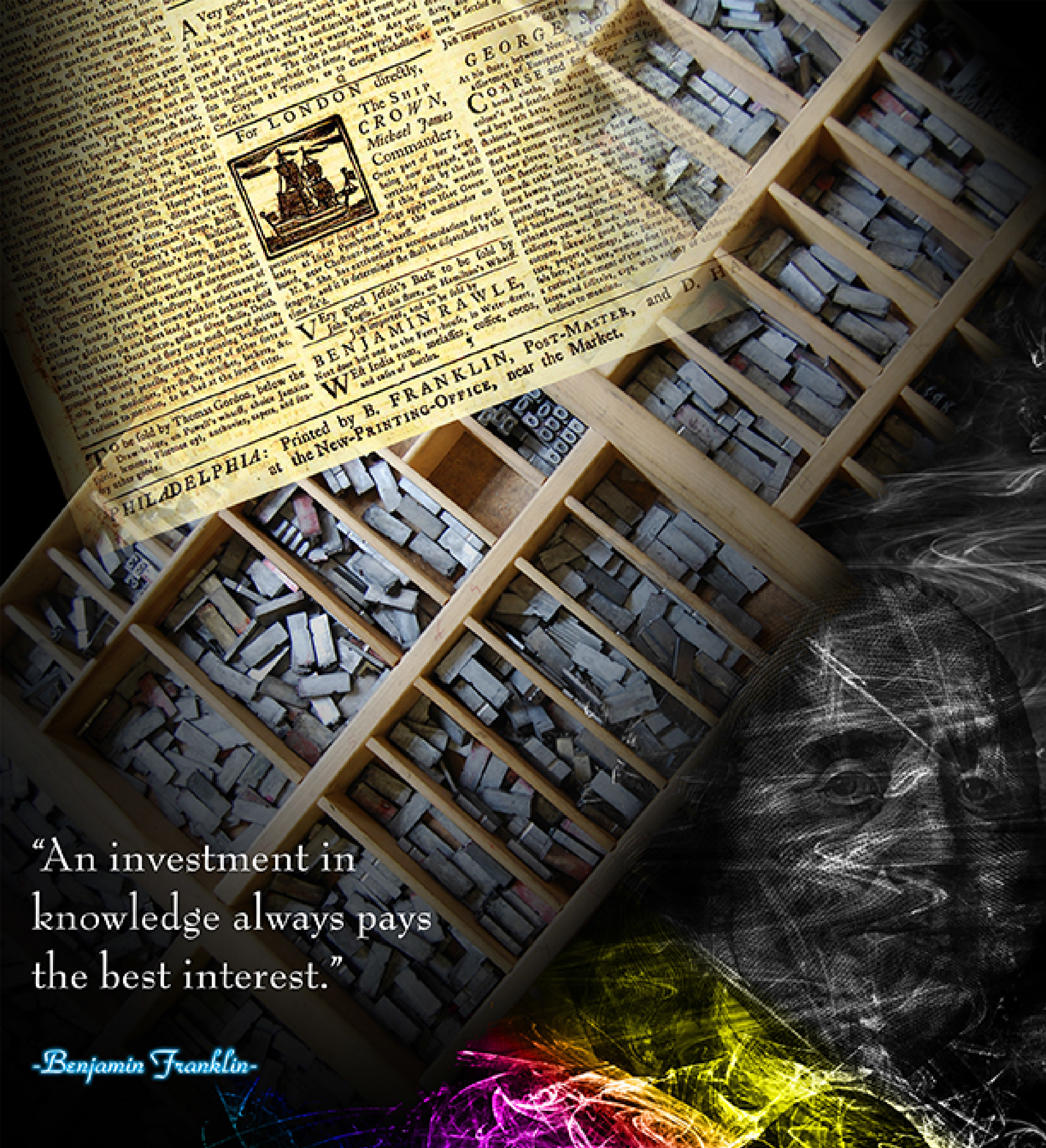

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An Analysis of Illuminant Metamerism for Contract Proofs

by Bruce Leigh Myers, Ph.D. • Rochester Institute of Technology

Hard copy contract proofing remains an integral part of many printing workflows. With the exception of actual press proofs, hard copy off-press proofing technologies can be segregated into two distinct types: halftone-based and continuous tone based.

In recent years, continuous-tone inkjet proofs have emerged as the dominant hard copy contract proofing technology. A 2005 report by the Print Industries Market Information and Research Organization (PRIMIR) entitled Dynamics and Trends in Color Proofing 2005–2010, states that “Inkjet proofing has grown to be far and away the most dominant form of hardcopy proofing” (p. 4).

Despite the domination of continuous tone ink jet technology for producing hard copy contract color proofs, some print buyers continue to demand halftone-based contract proofs, and today the materials and equipment to manufacture them off-press are available and widely supported. Among the most commonly cited reasons for print buyers demanding halftone-based proofs include the ability to accurately render the halftone dots that will be imaged on press; this allows those assessing the proofs the ability to predict potential screening artifacts, such as moiré patterns. These perceived benefits contribute to the ongoing viability of halftone based digital proofing technologies in the marketplace, despite the increased costs involved in producing these types of proofs versus continuous tone inkjet technologies. Additional relevant attributes, however, could separate digital halftone based proofs from their continuous tone inkjet counterparts.

It is critical that contract proofs represent the visual conditions of the final press sheet as closely as possible. One concern rising out of these conditions is the potential realization of a visual phenomenon known as illuminant metamerism. It is possible that proofs made using different technologies which, in turn, use different colorants as raw materials, could match a press sheet when viewed under one set of lighting conditions and display a visual mismatch under another (Berns, 2000). An examination of the degree of illuminant metamerism of inkjet inks versus that of digital halftone based proofing technologies is the specific goal of the present research.

Using a metric known as metamerism index, the research endeavors to provide useful information to investigate the potential presence of illuminant metamerism via the measurement of inkjet and digital halftone proofs, as compared to ink on paper press sheets.

While relevant industry specification committees recommend controlling for illuminant metamerism through the use of standardized viewing conditions, having a better idea of the relative degree of potential visual mismatch due to changes in illumination could be relevant for stakeholders in the graphic communications industry.

Metamerism index

Developed as a single number index, the metamerism index purports to demonstrate how well two objects that match when viewed under one illuminant will match under a second, different illuminant. The index is described in CIE Publication 15.2 (1986), Section 5.2, and is illustrated below.

Metamerism index =

$$\sqrt{(\Delta L_{n1}-\Delta L_{n2})^2+(\Delta a_{n1}-\Delta a_{n2})^2+(\Delta b_{n1}-\Delta b_{n2})^2}$$

Where $n1$ is the first, reference illuminant, $n2$ is the second illuminant, and Δ is the difference between the standard and sample

Method

All printed samples and proofs were provided from four different printing organizations representative of four-color process work adhering to the specifications outlined by IDEAlliance GRACoL 7. All measurements were taken using a single X-Rite SpectroEye $45^{o}/0^{o}$ Spectrophotometer which was factory calibrated to the XRGA standard and profiled using NetProfiler technology. A white ceramic tile was utilized as a backing material for all measurements. Materials measured included process color press sheets, two types of digital halftone proofs, and inkjet proofs.

A single instrument was used for all reported measurements to minimize potential variance due to inter-instrument agreement. For each reading, spectral values were recorded and colorimetric values, specifically CIELAB at illuminant D50 and illuminant A, were calculated. The readings from the press sheets were averaged to create the standard to be compared to the respective proofing methods. Each press sheet was measured, and spectral data were recorded at two or three different areas from the color bars on each sheet, depending on sheet width.

Proofs were obtained from each of two widely available digital halftone proofing technologies, as well as for various inkjet proofs, which served as the sample readings for the calculation of metamerism index. These proofs were measured using the same criteria and procedure as was utilized for the measurement of the press sheet standards.

Results

A factorial ANOVA was utilized to examine the categorical predictor variables (proofing process, color) with the single continuous criterion variable (metamerism index). It was ascertained that the inkjet proofs exhibit the highest average across all process colors (*M*=1.853, *SD*=1.230). Of the halftone proofing methods examined, halftone method two exhibited the lowest mean average (*M*=0.885, *SD*=0.603) while halftone method one exhibited a mean metamerism index value between the inkjet and halftone method two (*M*=1.374, *SD*=6.78). This finding suggests a main effect difference due to process. Further, when examining the total results, the obtained data indicate that cyan has the greatest potential for illuminant metamerism (*M*=2.234, *SD*=0.823), followed by Black (*M*=1.815, *SD*=1.070), Yellow (*M*=0.797, *SD*=0.208), and finally Magenta (*M*=0.595, *SD*=0.211). Descriptive statistics for metamerism index by process and condition are reproduced in Table 1.

In the subsequent analyses of the data, one goal here was to ascertain if the differences in metamerism index as calculated between the inkjet proofs and the two digital halftone methods is statistically significant. The various proofing methods can be described as processes: therefore these methods are categorized as "process" in subsequent tables.

A factorial ANOVA, which utilizes an F test to measure statistical significance, was the chosen method for this analysis. The examination of the interaction effects of "Process*Condition," as illustrated in Table 2 indicate that there are statistically significant differences between combinations of the digital halftone methods and the inkjet proofs. A Bonferroni post-hoc test was conducted to clarify the nature of the significant F test.

As indicated in Table 3, the data obtained indicate that, in the aggregate, inkjet proofs are more sensitive to metamerism than their halftone-based counterparts: the mean difference of –0.968 ($p<0.001$) between halftone process two and the inkjet proofs represented the greatest difference observed. Further, the observed mean difference of –0.479 ($p<0.001$) between halftone process one and the inkjet proofs was also statistically significant.

An additional analysis examined the mean differences of metamerism index for each of the process colors, categorized here as "condition," as illustrated in Table 4. As was previously discussed and illustrated in Table 1, cyan exhibited the highest overall mean in metamerism index, followed by black, then yellow and finally magenta. Table 4 illustrates the statistical significance of these mean differences.

Table 1: Descriptive Statistics for Metamerism index by Process and Condition

Process	Condition	*M*	*SD*	*n*
Halftone 1	Yellow	0.830	1.90	55
	Cyan	1.889	2.72	55
	Magenta	0.707	2.96	55
	Black	2.083	3.62	54
	Total	1.374	6.78	219
Halftone 2	Yellow	0.797	.245	54
	Cyan	1.374	5.69	55
	Magenta	0.509	0.094	54
	Black	0.479	0.066	54
	Total	0.885	0.603	217
Inkjet	Yellow	0.888	0.178	55
	Cyan	3.072	0.759	55
	Magenta	0.567	0.129	54
	Black	2.881	0.539	54
	Total	1.853	1.230	218
Total	Yellow	0.839	0.208	164
	Cyan	2.234	0.823	165
	Magenta	0.595	0.211	163
	Black	1.815	1.070	162
	Total	1.372	0.966	654

Table 2: ANOVA for Metamerism Index by Process and Condition

Source	SS	Df	M^2	F	Δ^2
Process	102.46	2	51.228	373.13***	0.538
Condition	299.56	3	99.853	727.30***	0.773
Process * Condition	119.19	6	19.865	44.690***	0.575
Error	88.14	642	.137	54	

****p < 0.001*

Having established the statistical significance of the main effects, the study turns to an investigation of the interaction effects. The data obtained indicate that the process color cyan exhibits the greatest difference in metamerism index for inkjet proofs when compared to the digital halftone proofing technologies. Further, the process color black also exhibited a higher metamerism index with the inkjet proofs than the second halftone proofing technology, and less of a difference when compared to the first halftone proofing technology. The colorants comprising the yellow and cyan exhibit much less of a difference regardless of the proofing technology examined. These observations are illustrated in Table 5, where effect tests were utilized to determine if differences observed in the interaction display plots are statistically significant.

Discussion

The results of the present research indicate that continuous tone inkjet proofs, as measured by metamerism index, are likely to show illuminant metamerism more readily when compared to digital halftone based proofing technologies. In addition, the process colors cyan and black demonstrate metamerism as measured by metamerism index to a greater degree than magenta or yellow. This finding underscores the realization that, like so many other attributes in color reproduction, the amount of expected process variance is frequently image dependent. Proofs manufactured from images with dominant cyan and black hues in critical areas may exhibit illuminant metamerism more readily than those with primary images comprised of magenta and yellow. This finding may have an influence on those working with images that utilize large amounts of gray component replacement (GCR) and undercolor removal (UCR), where neutral areas are replaced with black inks. If the black ink is more prone to illuminant metamerism when proofed, color professionals should be sensitive to this condition.

Table 3: Individual Bonferroni Comparisons for Metamerism index by Process

(I) Process	*(J) Process*	*M Difference (I – J)*	*SE*
Halftone Process 1	Inkjet Process	-0.479***	0.03545
Halftone Process 2	Inkjet Process	-0.968***	0.03553

****p < 0.001*

Table 4: Individual Bonferroni Comparisons for Metamerism Index by Condition

(I) Condition	*(J) Condition*	*M Difference (I—J)*	*SE*
Yellow	Cyan	-1.395***	0.0409
	Magenta	0.244***	0.0410
	Black	-0.976***	0.0410
Cyan	Magenta	1.639***	0.0409
	Black	0.419***	0.0410
Magenta	Black	-1.22***	0.0411

****p < 0.001*

While this study represents a potentially important initial step in examining potential factors contributing to illuminant metamerism in hard copy proofing workflows, there are several limitations that represent areas that future researchers may choose to examine. For example, this research examined metamerism index as limited to the solid process colors (cyan, magenta, yellow and black) for two different types of halftone-based proofs as well as for several types of inkjet proofs. The present research did not examine the metamerism indices of the substrates, overprints or neutral print densities, and did not examine non-process colors or overprints. Future researchers may choose to advance into these areas by examining these particular attributes.

In addition, the present research evaluated metamerism index using CIE Illuminant D50 as a reference, consistent

Table 5: Individual Bonferroni Comparisons for Metamerism index by Process and Condition

Condition	*(I) Process*	*(J) Process*	*Mean Difference(I—J)*	*SE*
Yellow	Halftone 1	Inkjet	-0.580	0.071
	Halftone 2	Inkjet	-0.091	0.071
Cyan	Halftone 1	Inkjet	-1.183***	0.071
	Halftone 2	Inkjet	-1.332***	0.071
Magenta	Halftone 1	Inkjet	0.140	0.071
	Halftone 2	Inkjet	-0.058	0.071
Black	Halftone 1	Inkjet	-0.789***	0.071
	Halftone 2	Inkjet	-2.402***	0.071

****p < 0.001*

with ISO3664:2009. The secondary illuminant selected was CIE Illuminant A, representative of incandescent light sources. Other illuminant combinations were not evaluated here, but could be examined in subsequent studies.

It is hoped that the results of the present research emphasize the importance of those working in color critical workflows to be more sensitive to the effect of illuminant metamerism, to call attention to the fundamental need to remain vigilant about standardized viewing conditions to ensure the valid assessment of proofs, and to help to promote the adoption and use of metamerism index into the standard operating procedures as a tool for quality assurance and communication purposes.

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