Journal of Imaging Science and Technology® 66(3): 030509-1–030509-7, 2022.

Acceptability-based Brand Color Tolerance, A Case Study

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Abstract. *The Pantone® Formula Guide (or Guide), printed using specially-formulated inks on specified substrates, has been used widely by brands to specify brand color aims. While the Guide is silent on brand color tolerance, there are two competing criteria that influence the brand color tolerance, i.e., perceptibility and acceptability. Perceptibility-based color tolerance focuses on "Can I see the difference?" and the permissive difference is in the just-noticeable difference (JND) region. Acceptability-based color tolerance, focusing on "Can I accept the outcome?", requires fit-for-use cases to identify what the just-acceptable difference (JAD) is. Instead of conducting psychometric tests, this research uses the 2019 Pantone® Formula (Coated) Guide, consisting of 2140 CIELAB colors, and data analyses of the "neighboring color difference" to investigate what is the acceptability-based color tolerance. The result shows that the acceptability-based color tolerance (3 ΔE_{00}) has more margin than the perceptibility-based color tolerance (2 ΔE_{00}).*
[DOI: 10.2352/J.ImagingSci.Technol.2022.66.3.030509]

1. INTRODUCTION

1.1 *What Is Brand Color?*

Brand color is a powerful tool to enhance the logo and the appearance of the merchandise. Brand color on the product adds to product differentiation. Brand color in packaging and promotional materials enhances brand recognition and brand loyalty.

1.2 *Specifying Brand Color Aims*

Many brand colors are specified in terms of Pantone® numbers [1]. For examples, the Coke® Red is specified by Pantone® 2347C, John Deere® Green is specified by Pantone® 364C, and IBM® Blue is specified by Pantone® 2718C (Figure 1).

1.3 *Reproducing Brand Colors by Different Printing Methods*

Brand color reproduction and its conformity assessment require aims and tolerances. Brand color aims are specified by designers with the use of the Guide. Designer's job data, including color, graphics, and texts, are then converted to the prepress data in two ways: spot color and process color.

When the prepress data is separated as spot colors, they are printed by separate printing plates using specially-formulated inks. On the other hand, when the prepress data is separated as process colors, they are printed using a fixed set of process inks (CMYK, more-than-CMYK). Although the cost of reproducing brand colors as process color is lower, not all Pantone® colors can be accurately reproduced by the process color. Thus, the magnitude of the brand color tolerance becomes an issue.

1.4 *Perceptibility-Based Tolerance versus Acceptability-Based Tolerance*

The brand color tolerance is the permissive color difference between the Guide and the printed color. There are two competing criteria in specifying brand color tolerances [2]: (1) when tolerance is perceptibility-based, it focuses on "Can I see the difference between the color standard and the printed sample?" The magnitude of the tolerance is often in the just-noticeable difference (JND) region, and (2) when tolerance is acceptability-based, it requires psychometric studies with a focus on "Can I accept the outcome?" or "Does it fit for use?" Ultimately, it raises the question, "What is the difference between JND-based tolerance and JAD-based tolerance?"

As brands continue to look for ways to stand out among their competitors, they have to be willing to take the associated risks and benefits. At the same time, printers must find out pros and cons of the two printing methods (spot color and process color) in relation to the brand's expectations in terms of aims, tolerances, and costs.

1.5 *Pantone® Formula Guides*

The first edition of the Pantone® Formula Guide was developed in 1960s by Lawrence Herbert while working for a printer in New Jersey. He created a collection of solid color specimens by modifying multiple ink wells and a blanket cylinder on a press. Different ink formulations were based on two or three of the basic inks, including the white and the black inks. Designers find the fan deck useful when visualizing and specifying brand colors by Pantone® numbers. In turn, printers use the Guide for ink mixing and color-matching on press [3].

A unique point about this paper is that the tolerance is not used to assess the reproduction quality of the Guide.

Received Oct. 25, 2021; accepted for publication Jan. 14, 2022; published online March 9, 2022. Associate Editor: Teruaki Mitsuya.
1062-3701/2022/66(3)/030509/7/$25.00

Figure 1. Examples of brand color specified by Pantone® numbers.

Instead, the Guide itself is used to study the JAD-based color tolerance.

2. RESEARCH PROJECT

2.1 *Problem Statement*

Tolerance is a man-made decision. Pantone® manufactures its Pantone® Formula Guide using its 28-fountain offset press [3]. Color tolerance is necessary to ascertain the conformity of the Guide to specifications. Not knowing the specific nature of the tolerance used leads to an interesting question, "Is JAD-based color tolerance the same as the JND-based color tolerance?" This question is not only relevant to the graphic arts industry, but also to color-critical applications in other industries, including photography, textile, fashion, etc.

2.2 *Hypothesis*

It is hypothesized that the acceptability-based tolerance is not the same as the perceptibility-based tolerance. In order to test the hypothesis, the "neighboring color differences" from the Pantone® Formula Guide are analyzed statistically to derive the acceptability-based color tolerance.

2.3 *Neighboring Color Differences*

When analyzing the neighboring color differences from the V4 Color List, extra-large color differences will result due to cross-page (ΔE_{00} between the last color of a page and the first color of the next page) and pages containing basic colors. Like separating wheat from the chaff, these extra-large color differences are excluded before analyzing the central tendency of the remaining ΔE_{00} distribution.

3. LITERATURE REVIEW

3.1 *Factors Influencing Color Difference*

"Color difference" may mean "measured difference" or "visual difference" between a sample and a target color. The assessment of the "measured difference" has been standardized worldwide, by the CIE, the international authority on light and color. CIE specified the $\Delta E*_{ab}$ metric in 1976. ISO/TC 130, the international standardization body in the printing industry, adopted the $\Delta E*_{ab}$ metric in the printing standards since 1996. Today, ΔE_{00} is the recommended color difference metric by the CIE because it correlates better with color perception.

When the permissive color difference, or the color tolerance, is specified by physical samples, the target color is the "centroid" and the allowed color differences are the "boundary" colors. When comparing the target color and the boundary colors visually, the following color variables are specified: lighter, darker, redder, greener, bluer, or yellower [4].

It is difficult to standardize the assessment of the "visual difference" because there are many factors, as described below, that increase the uncertainty of the perceptibility-based tolerance.

3.1.1 There is a connection between the light source, physical stimuli, and the visual sensation of an observer. From the light source point of view, the spectral power distribution, viewing geometry, and intensity of the illumination are major factors. As such, metamerism [4] is a "conditional match" whereby spectral properties of the sample and its target color are different, but the perceived colors are matched in one illumination, but not matched in other illuminations.

3.1.2 The eye adapts to various illumination conditions. Dark adaptation is the increase in eye's sensitivity in dark illumination. Light adaptation is the decrease in eye's sensitivity in bright illumination. Color adaptation is the changes in the eye's spectral sensitivity when eye is exposed to chromatic light stimulation [5]. The effect of the color adaptation, also known as color constancy, is for objects to retain their color despite changes in the spectral quality of the light.

3.1.3 From the visual comparison point of view, the eye is most sensitive when the sample and its target color are seen juxtaposed as two-halves of a visual field. The sensitivity of the eye diminishes when the sample and its target color are viewed side by side. The sensitivity of the eye further diminishes when the sample and its target color are viewed successively or one at a time [6]. This is why the answer to the question, "how many colors do you see?", varies.

3.1.4 From psychophysical point of view, there is a connection between physical stimuli and visual sensation of an observer [7]. By carefully arranging the stimuli, the effect known as "simultaneous contract" demonstrates seeing the same color as two different colors due to the surround difference. The effect, known as "assimilation", demonstrates seeing the same color as two different colors due to neural activities in neighboring regions of the retina. In both cases, the stimulus situation must be carefully arranged in order to demonstrate these visual effects.

Figure 2. The 2019 Pantone® Formula Guide (Coated).

3.2 *Just-Noticeable Difference (JND)*

In psychology, the just-noticeable difference (JND), also known as the difference threshold, is the minimum level of stimulation that a group of observerscan detect 50 percent of the time [8]. For example, if a group of participants were asked to examine two sound signals, the just-noticeable difference (JND) would be the minimum difference between the two sounds that they could sense half of the time. The JND concept also applies to other human senses, e.g., vision, smell, touch, etc.

The concept of just-noticeable difference was further studied by two psychologists, Ernst Weber and Gustav Fechner [8]. The Weber-Fechner Law states that if a sound signal is specified and then altered to a different sound level that the participants could just tell half of the time, the just-noticeable difference can apply to other sound signals as a proportion of the original stimulus.

Brand color tolerance has been based on the perceptibility criterion, i.e., the permissive difference is in the just-noticeable difference (JND) region. In many instances, 2 ΔE_{00} has been used by brands, including Pantone Company [9], and in color-matching studies [10], as the tolerance in the spot color reproduction.

In an attempt to assess the spot color tolerance in offset printing, Bertholdt [11] measured many laboratory-generated ink samples, including 14 Pantone primary colors, and reported that significant color deviations exist between the colors specified and the color samples measured. In fact, 2 ΔE_{00} was considered too tight of a deviation tolerance for spot colors in offset printing.

3.3 *Just-Acceptable Difference (JAD)*

Brands specify their logo requirements, including color, in their brand manuals. However, brands do not have color deviation requirements specified in their brand manuals [12]. Although acceptable color tolerances are assumed to be greater than the perceptibility-based tolerance, there is no framework, nor experimental data, to provide an explicit solution.

Color-tolerance research studies require the specification of the stimuli, the number of subjects, their genders, viewing conditions, instructions, and psychometric data collection and analysis to ascertain what the just-acceptable difference (JAD) is. Instead of following the usual psychometric research method, this research relies on the colorimetric data from the Pantone® Formula Guide as the source, coupled with a unique data analysis method to explore the just-acceptable difference (JAD).

The just-acceptable difference (JAD) is ideal for multi-component products manufactured by multiple suppliers in different locations using a variety of processes. When acceptable color deviations of the finished product are agreed upon, buyers will get the color they want and suppliers will have the flexibility they need to compensate for slight color shifts that result from normal process variations [2].

4. METHODOLOGY

4.1 *Resources*

The 2019 version of the Pantone® Formula (Coated) Guide was used in this research. The Guide contains 307 pages or a total of 2161 colors (Figure 2). Each page contains 7 colors with similar hues but varying lightness and chroma. Each color is associated with a unique Pantone® number and an ink formulation.

The Pantone® V4 Color List, a text file, available from the Pantone® Color Manager, was also used in the research. The V4 Color List contains 2140 Pantone® numbers and CIELAB values. The difference between the Guide (2161 colors) and the List (2,140 colors) or 21 (2161–2,140) colors is due to the inclusion of seven Pantone® pastels

Figure 3. Pantone® 165C and its neighboring colors in the Pantone® Formula Guide.

(page 1.2), seven Pantone® neons (page 1.3), and seven Pantone® metallics (page 1.4) in the Guide.

4.2 *Assumption and Limitations*

When the tolerance is acceptability-based, this research assumes that the analysis of neighboring color differences in a database reveals what the just-acceptable difference (JAD) is.

In this research, the just-acceptable difference (JAD) depends on a specific database, i.e., the 2019 Pantone® Formula Guide (Coated). Other Pantone® color guides, including the Uncoated Guides and the process-color CMYK Guides, are outside the scope of this research.

Only color deviations (between two colors) are studied. Color variations (between many colors and their average) are outside the scope of this research.

4.3 *Key Concepts*

When a brand owner decides on a brand color, for example, Pantone® 165C (the fourth color in Figure 3), from the Pantone® Formula Guide, it is expected that its neighboring colors (Pantone® 164C and Pantone® 166C), although similar, are different. In other words, a just-acceptable difference (JAD) is no greater than one-half the difference between the target color and its neighboring colors. It also means that the maximum color difference between two color samples or batches will not be greater than the color difference between the target color and its neighboring colors.

4.4 *Experimental*

Neighboring color differences vary from color to color in the Pantone® Formula Guide. In order to find the just-acceptable difference (JAD) objectively, the following procedures and decision rules are used:

4.4.1 Analyze the color characteristics of typical Pantone® 7-color pages.

4.4.2 Compute neighboring color differences (ΔE_{00}) in the Pantone® V4 Color List.

4.4.3 Establish cut-off conditions to remove extra-large color differences from the distribution.

4.4.4 Analyze central tendencies (mean, median, and mode) of the ΔE_{00} distribution as a function of the cut-off conditions.

4.4.5 Identify the average neighboring color difference whereby central tendencies converge.

4.4.6 Determine the just-acceptable difference (JAD) to be one-half (or 50 percent) of the average neighboring color difference.

5. RESULTS

5.1 *Color Characteristics of the Pantone® 7-Color Pages*

Figure 4 (left) illustrates four (yellow, red, blue, and green) Pantone® pages. The light color is situated at the top of the page and gradually darkens toward the bottom of the page. The color with the maximum chroma is located in the (4th position) middle of the 7-color page.

Fig. 4 (center) illustrates these colors in the a∗ b∗ diagram. To explain, the yellow page shows that these seven Pantone® colors have similar hue angles, different chroma values, but without the lightness information.

Fig. 4 (right) illustrates the same four 7-color pages in the L∗C∗ diagram. If we focus on the yellow page again, it shows that any two neighboring colors vary in chroma and in lightness, but not the hue angle information.

By examining the neighboring color differences in each of the four (yellow, red, blue, and green) pages, Figure 5 indicates that there are 6 neighboring color differences in a 7-color page. Fig. 5 also indicates that the magnitudes of the neighboring color differences vary, i.e., most are less than 10 ΔE_{00}, some are between 10 ΔE_{00} and 20 ΔE_{00}, and few are greater than 20 ΔE_{00}.

5.2 *Cut-Off Conditions that Remove Extra-Large Color Differences from the Distribution*

Figure 6 illustrates the neighboring color difference (ΔE_{00}) as a bar chart from three consecutive pages, containing Pantone® 165C. By treating the three pages (21 colors) as a whole, there are 20 neighboring color differences. Notice that the cross-page color differences are very large (>30 ΔE_{00}). Like separating wheat from the chaff, the cut-off is essential in order to remove extra-large color differences from the distribution prior to the central tendency analysis.

5.3 *Central Tendencies of the ΔE_{00} Distribution as a Function of the Cut-Off*

Figure 7 shows a histogram of all (2139) neighboring color differences (ΔE_{00}) from the Pantone® V4 Color List. Before applying the cut-off, the histogram shows skeweing, indicating different mean, median, and mode.

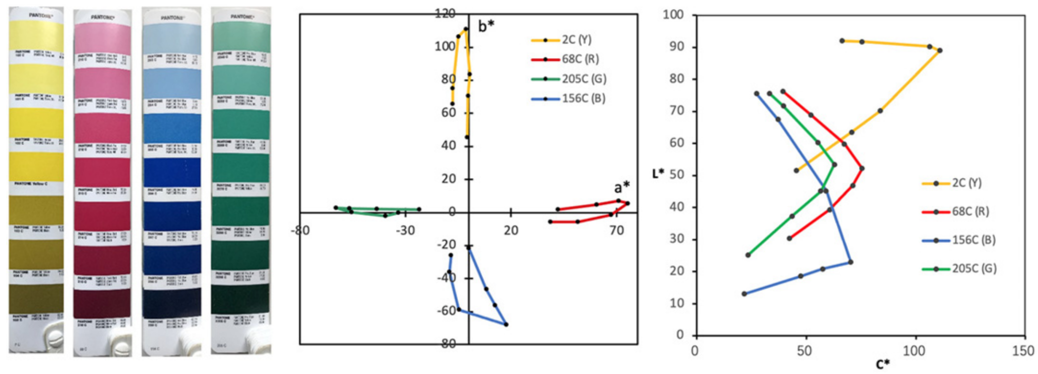

Figure 4. Four 7-color pages (left) in the a∗b∗ plot (center) and the L∗C∗ plot (right).

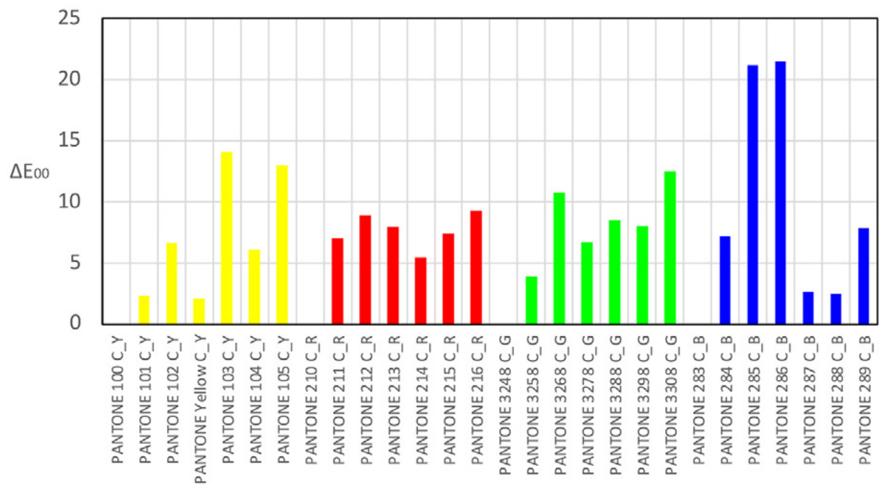

Figure 5. Neighboring color difference (ΔE_{00}) in the four (RGYB) within-pages.

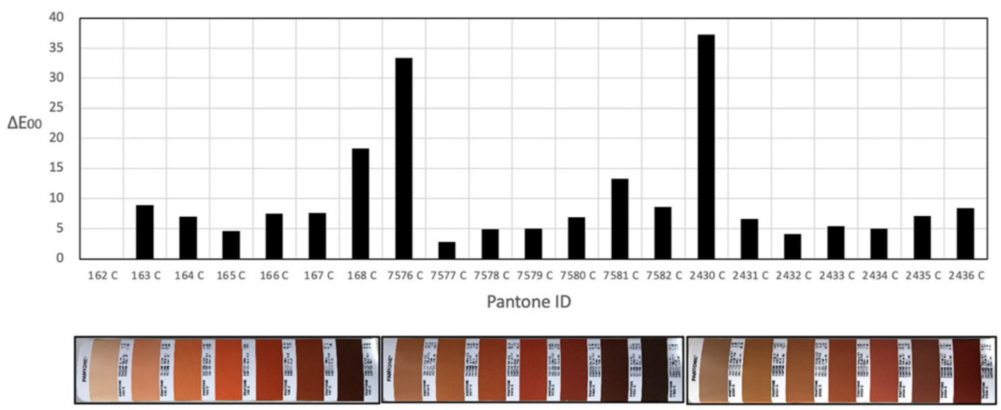

Figure 6. Neighboring color differences from three consecutive pages.

To observe how the distribution is affected by the cut-off, extra-large ΔE_{00} values are excluded progressively from greater than 40, 30, 20, to 10 ΔE_{00}. As shown in Table I, when samples greater than 40 ΔE_{00} is excluded, 92% of the data remains; the mean (9.6 ΔE_{00}), the median (7.4 ΔE_{00}), and the mode (6 ΔE_{00}) are very different. When greater than 30 ΔE_{00} is excluded, 88% of the data remains, but the central tendencies are not converging until the cut-off is set at 10 ΔE_{00}.

Figure 8 is a graphic depiction of Table I, i.e., when the cut-off is at 10 ΔE_{00}, the central tendencies (mean, median, and mode) of the remaining (65%) distribution converge to 5.9–6 ΔE_{00}. In other words, by analyzing the neighboring color differences no greater than 10 ΔE_{00}, the

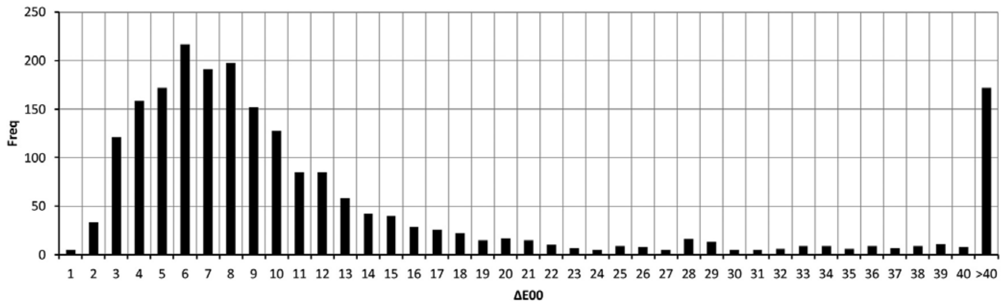

Figure 7. Histogram of all neighboring color differences (ΔE_{00}).

Table I. Central tendency (ΔE_{00}) as a function of the cut-off.

ΔE_{00} excluded	None	$>40\ \Delta E_{00}$	$>30\ \Delta E_{00}$	$>20\ \Delta E_{00}$	$>10\ \Delta E_{00}$
# Samples	2139	1968	1889	1797	1381
% Total	100%	92%	88%	84%	65%
Max	93.3	40.0	30.0	20.0	10.0
Mean	13.0	9.6	8.5	7.7	5.9
Median	7.9	7.4	7.2	7.0	5.9
Mode	6.0	6.0	6.0	6.0	6.0

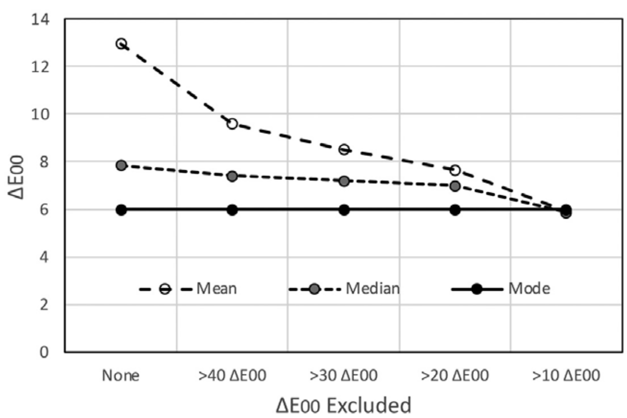

Figure 8. Central tendency of ΔE_{00} distribution as a function of the data exclusion or cut-off.

average neighboring color difference is 6 ΔE_{00}. Notice that the mean and the median are affected by the cut-off and the mode (6 ΔE_{00}), is independent of the cut-off.

5.4 *The Just-Acceptable Difference (JAD)*

When the cut-off or the maximum neighboring color differences is set at 10 ΔE_{00}, the average neighboring color differences converge to 6 ΔE_{00}. The just-acceptable difference (JAD), being one-half (or 50 percent) the average neighboring color differences, is 3 ΔE_{00}.

This case study asks the question, "Is JAD-based color tolerance the same as the JND-based color tolerance?" By analyzing the neighboring color differences in the Pantone® Formula Guide, this research concludes that the JAD-based color tolerance (3 ΔE_{00}) has more margin than the JND-based color tolerance (2 ΔE_{00}).

6. DISCUSSIONS

6.1 *Brand Color Tolerance by Two Opposing Criteria*

Perceptibility and acceptability are two different criteria in determining brand color tolerances. Like a paradox, these two criteria are partially conflicting and partially complementary. The paradox can be solved by an "*and*" solution, i.e., the brand color tolerance shall be 3 ΔE_{00}, *and* should be 2 ΔE_{00}. According to the ISO/IEC Directives [13], "shall" means "must" and "should" means "nice to have".

6.2 *Brand Color Tolerance by Two Different Printing Methods*

Process color printing has more color deviation factors than spot color printing. If the brand color tolerance is 3 ΔE_{00} when using spot color inks, more tolerance should be allowed when using process color inks.

7. CONCLUSION

Recognizing that the brand color tolerance should not be based on the perceptibility criteria, this research hypothesizes that an acceptability-based color tolerance can be determined from analyzing the neighboring color differences from a Pantone® color library. This research is a case study that determines the brand color tolerance based on the acceptability criteria from the 2019 Pantone® Formula Guide. Like separating wheat from the chaff, the sampling methodology requires the exclusion of extra-large color differences that are greater than 10 ΔE_{00} from the Pantone® Color List. In doing so, the central tendency of the neighboring color differences (mean, median, and mode) converge to 6 ΔE_{00}. Using "one-half of the average difference" as the rule, a reasonable brand color tolerance is no greater than 3 ΔE_{00}.

8. FURTHER RESEARCH

The Weber-Fechner Law suggests that the just-noticeable difference is not a constant, but a proportion of the original stimulus [8]. The Weber-Fechner Law is not followed in spot color printing because the color tolerance is treated as a constant. This is a topic for further research.

Not all brand colors have Pantone® designations; finding an acceptability-based tolerance, based on the analysis of the neighboring color differences in other color libraries, like Munsell® Book of Color (over 1,600 samples on 40 constant-hue pages), is also recommended.

The packaging printing industry is made up by different stakeholders. It will be useful to conduct a survey among industry stakeholders, including brands, designers, prepress houses, printers, etc., to find out (1) their understanding of the brand color quality as visualized and as measured, (2) their confidence in the acceptability-base tolerance and the perceptibility-based tolerance, and (3) their willingness to communicate the risks and the benefits of each color tolerance method to other stakeholders.

ACKNOWLEDGMENT

The authors wish to thank Professor Chuck Spontelli and Mr. William Birkett sincerely for reviewing the manuscript and providing helpful comments.

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