Buying From Web2Print Storefronts: Color Managed or Caveat Emptor?

Erica B. Walker, Suzanne H. Edlein, and Dr. David E. Barrett

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Abstract

Web2Print is a multi-billion dollar industry with hundreds of providers opting to offer online print ordering to customers. A print provider can choose from dozens of software solutions according to Web2PrintExperts.com. There are many aspects to consider when tying current internal and external processes into a new software solution, and perhaps color-management should be high on the provider's list of important factors to consider. As online shopping and mobile purchasing continues to grow, we wanted to ask, "what happens to my color?"

Many factors affect color consistency throughout the capture, ordering, and printing processes. Some of these include: the initial capture device, the conversion from RGB to CMYK for printing, conversion to PDF (most W2P request PDF files), the print provider's RIP conversions, the specific press, color specifications and standards set by the print provider, and vendor ink consistency, among others. Even with industry standards such as GRACoL and SWOP it is difficult to control all the variances the consumer introduces into the system. Although, there are many questions about color consistency and Web2Print that could and should be asked, the overall question this study addresses is "What happens to the expected color in our files when we upload them to ten popular Web2Print portals?"

With a multifactor analysis of variance of over 7200 L*a*b* readings, we found that in the GRACoL CMYK color space, the average ΔE value across multiple colors is slightly smaller than in the RGB color space. Grey tones measure the highest ΔE values in both color spaces- RGB and CMYK- than any other color group. Additionally, skintones are slightly closer to their intended values in the GRACoL color space. All print providers attained the lowest ΔE values, and therefore the closest visual match, in the grey tones regardless of the provided color space.match, in the grey tones regardless of the provided color space.

Clemson University Department of Graphic Communications and
Clemson University Eugene T. Moore School of Education

Introduction

As we began to discuss this research study, we found that there were many questions about color consistency and Web2Print that could and should be asked. The overall question this study was centered upon is "What happens to the expected color in our files when we upload them to ten popular Web2Print portals?" Specific questions explored include:

Can we expect to receive a printed piece that matches the L*a*b* values of the file submitted; and, do the results vary based on the color space of the file submitted?

Is there a correlation between color quality, price, and delivery speed?

Do consumer rankings of visual color match to a target correlate to the grand mean ΔE rank of the print providers?

What is a consumer's tolerance for acceptable color differences based the grand mean ΔE?

Methodology

The methodology for this study centers around four main points:

- Determine how the L*a*b* values shift between the file and the print
- Determine if print output can be controlled with file type/embedded profiles
- Investigate consumer's color discrimination and threshold for color shifts

Original artwork was designed by Jonathan Balcombe, a Clemson University Department of Graphic Communications student, class of 2015, in Adobe Illustrator using predetermined spot colors. Layout work was completed by Emily Martin, a Clemson University Department of Graphic Communications graduate student, class of 2014. The vector artwork was based on an original photograph and integrated 10 out of 24 spot colors from the X-Rite ColorChecker using the L*a*b* values for each spot color patch. Colors from the X-Rite ColorChecker Chart were used because the color patches have spectral reflectances intended to mimic those of natural objects such as human skin, foliage, and flowers, as well as neutral greys as detected by typical color photographic film.

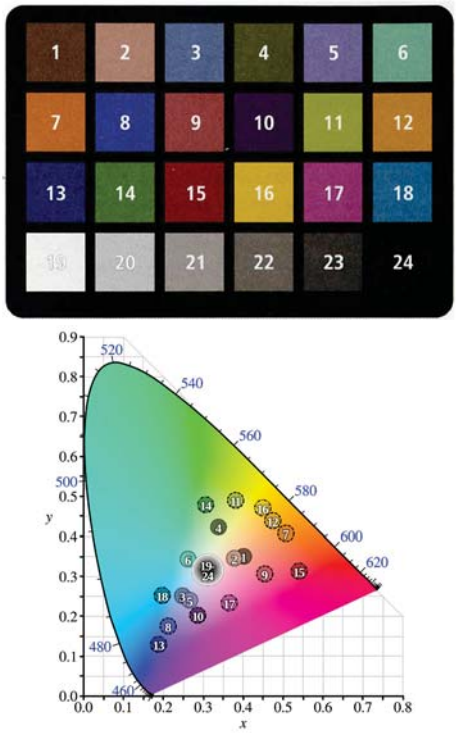


Figure 1: *X-Rite ColorChecker Chart, shown above, including their locations on the visual spectrum*

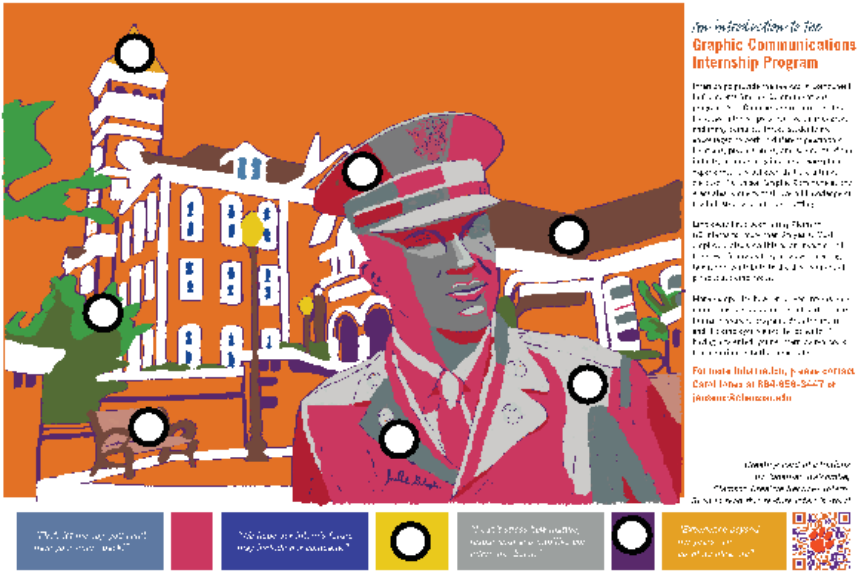


Figure 2: *Vector art postcard with 10 measurable patches of spot colors from the X-Rite ColorChecker target; patches indicated by white circles with black outline*

Each print provider received orders for two different versions of the vector art postcard, each order separated by at least a week to ensure separate printing days. Version one was RGB with AdobeRGB color space applied and no further color management. This version was created to mimic consumer behavior, allowing the print provider's RIP to process the file normally. Version two was CMYK color space with GRACoL 2006 specifications embedded in the PDF.

The vector art postcard was ideal for providing accurate measurements of the color patches, see figure 2, because each color patch was printed in a minimum of quarter-inch sized squares of a solid spot color filled with a predetermined LAB value.

File Preparation: AdobeRGB Vector Postcard
Adobe Illustrator® steps for preparing the AdobeRGB Vector file, see figures 3-5.

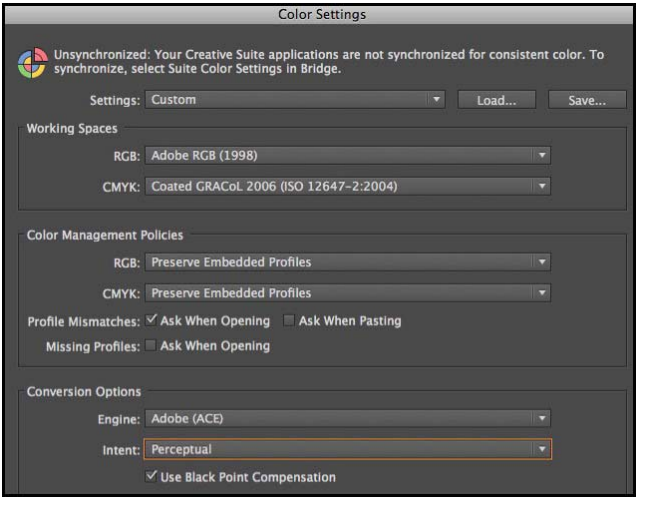


Figure 3: *Color Settings-Working spaces Adobe RGB (1998), RGB Color Management Policies: Preserve Embedded Profiles*

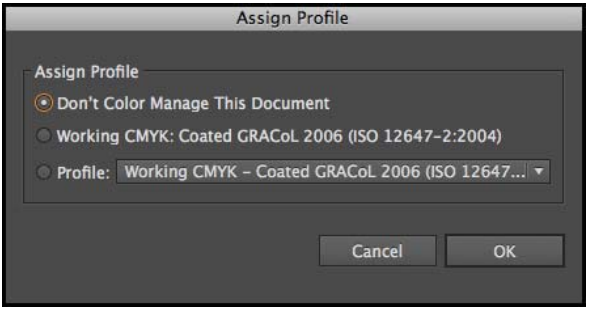


Figure 4: *Assign Profile-Don't Color Manage this Document selected*

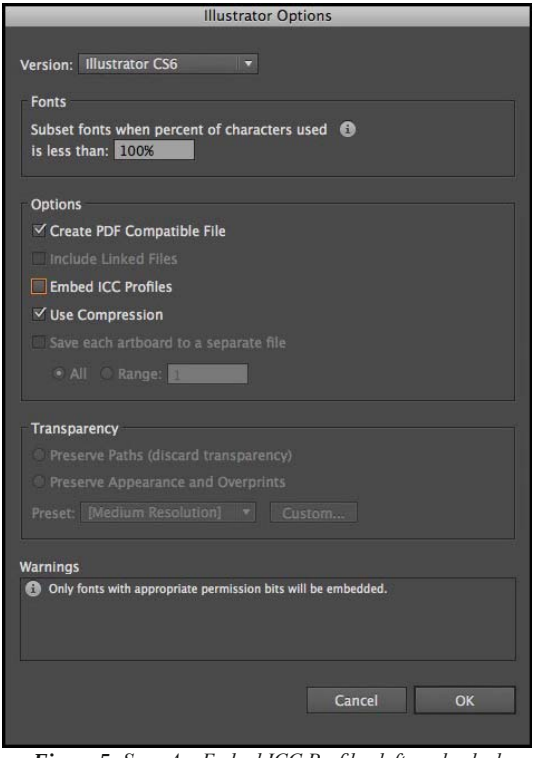


Figure 5: *Save As- Embed ICC Profiles left unchecked*

File Preparation: GRACoL 2006 Vector Postcard

Adobe Illustrator® steps for preparing the GRACoL Vector file, see figures 6-9.

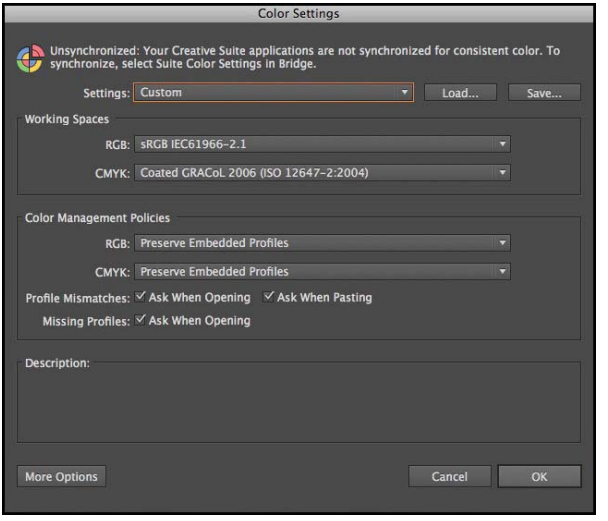


Figure 6: *Color Settings- Working spaces CMYK Coated GRACoL 2006, CMYK Color Management Policies: Preserve Embedded Profiles*

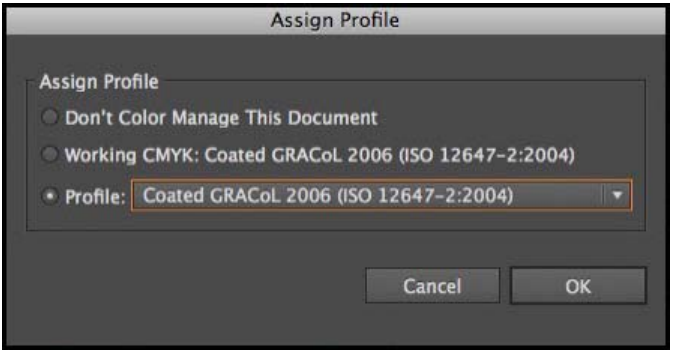


Figure 7: *Assign Profile- Coated GRACoL 2006 selected*

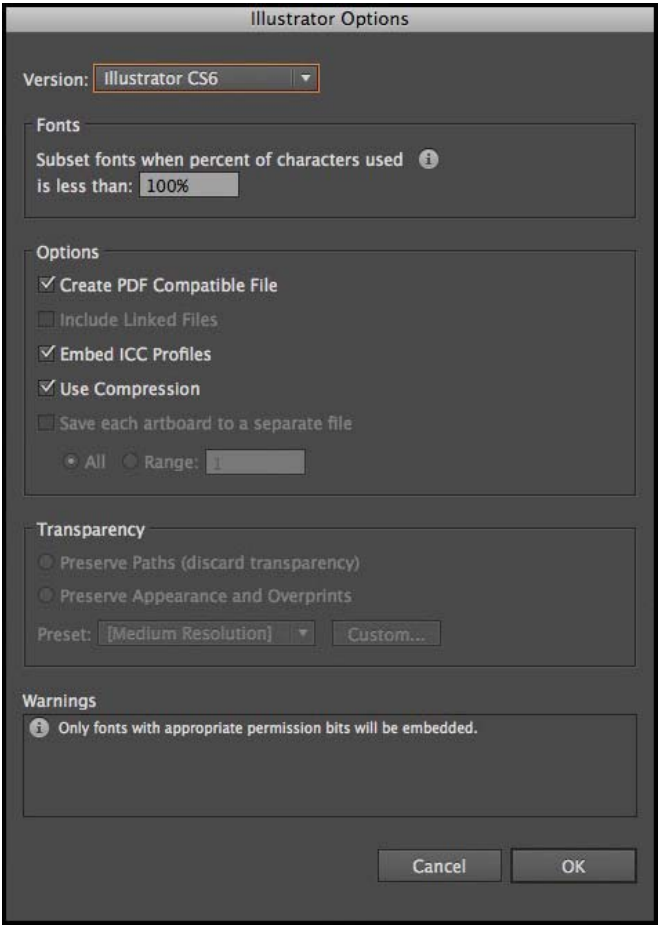


Figure 8: *Save As- Embed ICC Profiles checked*

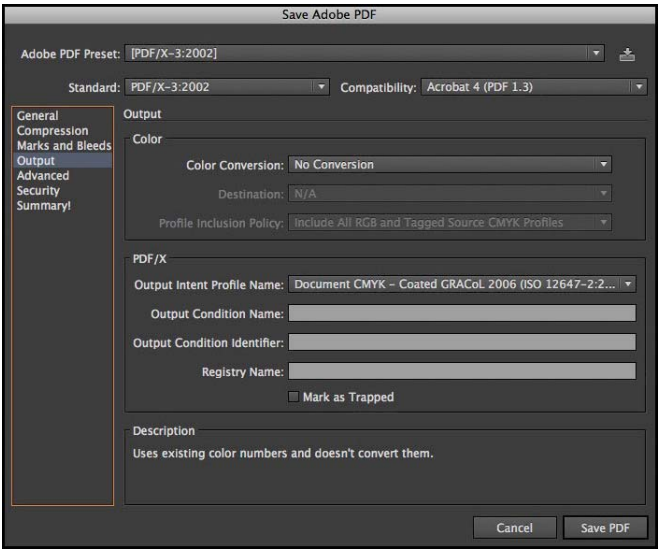


Figure 9: *Save As pdf- No Conversion checked*

Raster/Vector Postcard

A second postcard was created in order to provide an opportunity for a visual survey of a raster image, see figure 10. The raster/vector postcard included the raster image for the visual comparison portion of the study. Once again, there were two different versions of the raster/vector art postcard, ordered by at least a one week apart to ensure separate press runs. Version one was RGB with AdobeRGB color space applied and no further color management. This version was created to mimic consumer behavior by using RGB working space without further profiles applied, allowing the print provider to process the file normally. Version two contained a CMYK raster image with GRACoL 2006 specifications embedded.

Figure 10: *Raster/vector art postcards*

File Preparation: AdobeRGB Raster Image

Adobe Photoshop® steps for preparing the RGB Raster image, see figures 11-13.

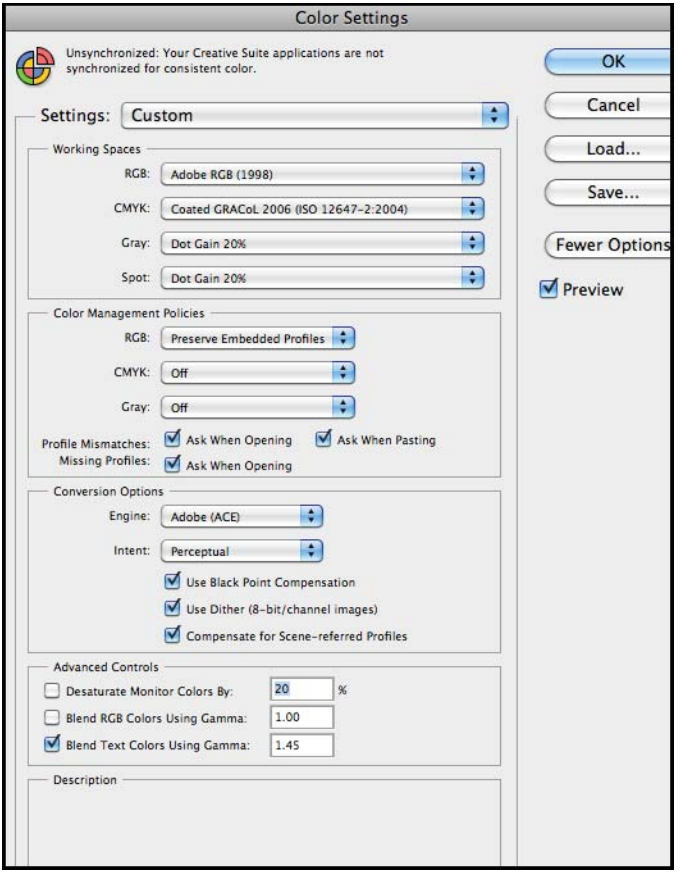


Figure 11: *Color Settings- Set Working Spaces Adobe RGB and Color Management Policies to Preserve Embedded Profiles*

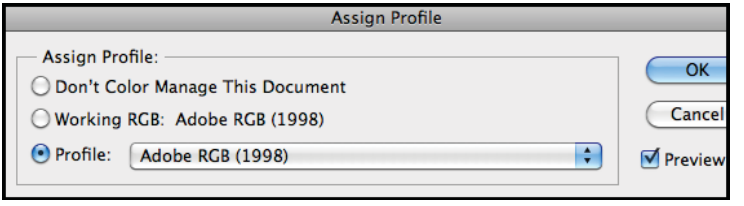


Figure 12: *Assign Profile- Assign Adobe RGB (1998) profile*

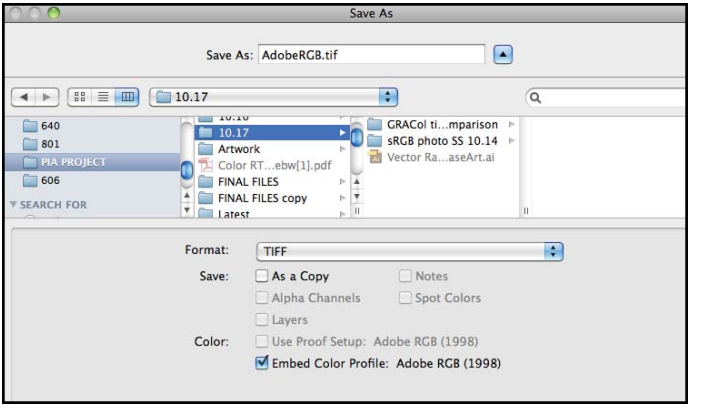


Figure 13: *Save As- Embed Color Profile is selected and set to Adobe RGB (1998)*

When placing the AdobeRGB raster image into the Adobe Illustrator® layout, the following steps were made:

1. Color Settings: Preserve Embedded Profiles
2. Assign Profile: Don't Color Manage This Document
3. Exported as jpeg for final file upload

File Preparation: GRACoL Raster Image

Adobe Photoshop® steps for preparing the GRACoL CMYK raster image, see figures 14-18.

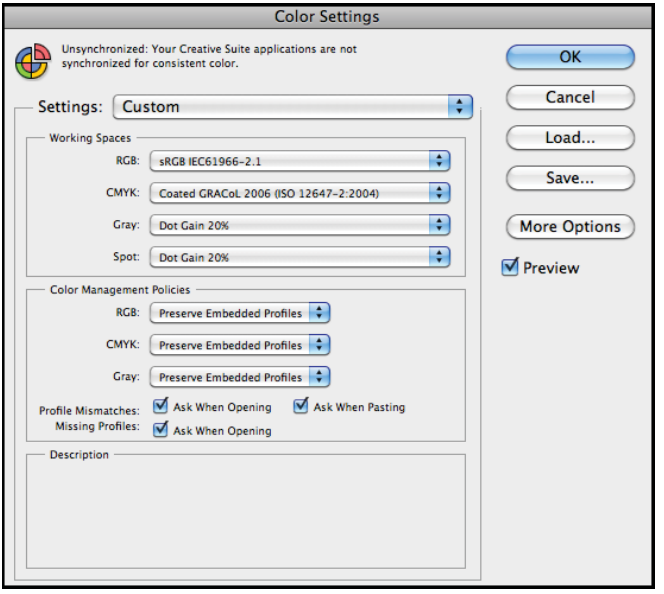


Figure 14: *Color Settings- Set Working Spaces CMYK GRACoL and Color Management Policies Preserve Embedded Profiles*

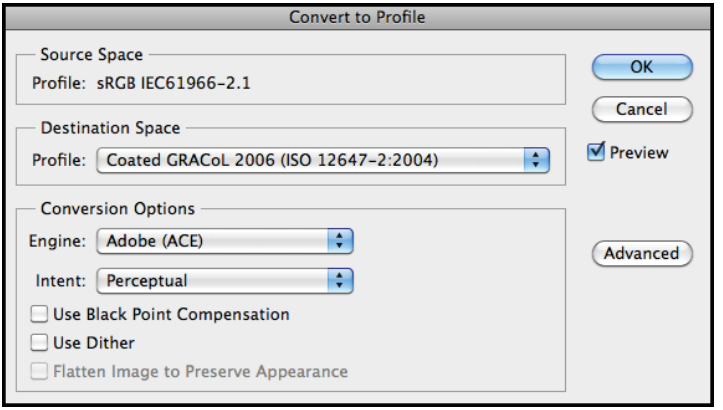


Figure 15: *Convert to Profile- Destination Space Coated GRACoL 2006 profile*

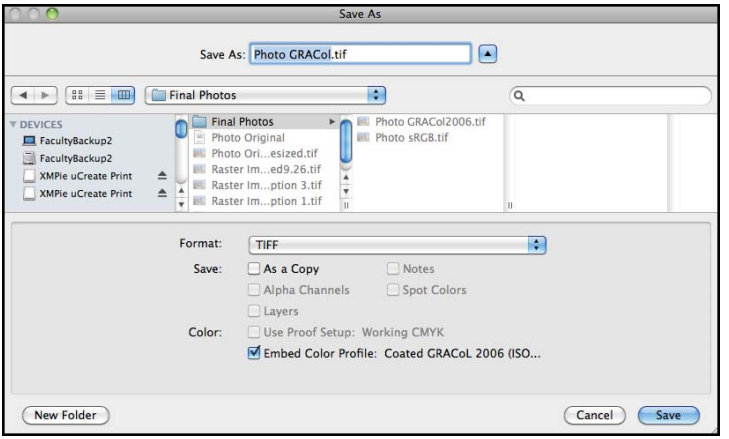


Figure 16: *Save As- Embed Color Profile checked*

When bringing the GRACoL raster image into the Adobe Illustrator® layout, the following steps were made:

1. Color Settings: Preserve Embedded Profiles
2. Assign Profile: Coated GRACoL 2006
3. File converted to pdfx3 for submission to the print provider

Ordering the Postcards

Orders were placed at ten print providers using their Web2Print online ordering system. This research was conducted as a blind study, therefore none of the print providers involved in the study were aware that we were measuring their resultant product. Blind studies have both advantages and disadvantages:

Advantages - print providers will treat our order the same as a normal consumer's order and our job will be run according to their standard workflow. Because of the blind study format, we knew that our order was treated just like a typical consumer's order.

Disadvantages - because of the blind study format, we have significantly less knowledge regarding the print provider's systems. We didn't get to ask what RIP they used, which press(es) the job was run on, or what standards or specifications they keep in regards to color. In essence, due to this choice in methodology, we weren't able to explore the "how and why" aspects of our findings.

For this study, we felt that the advantages outweighed the disadvantages of using a blind format. We would recommend a different format for a follow-up study in order to be able to explore those additional questions.

It is important to note that because this is consumer level ordering the only proofing option is an uncontrolled digital soft proof on a computer monitor. The customer approves that they are satisfied with the color to be printed based solely on what they are seeing on their personal computer monitor.

Figure 17: *Samples received from multiple print providers, the image on the left are from the RGB color space prints and the samples on the right are CMYK, with GRACoL profile embedded*

File Measurements

Two types of measurements:

1. L*a*b* measurements using an X-Rite 530 Spectrodensitometer
2. Visual check comparing the overall color accuracy of the raster images

L*a*b* Measurements

Ten of the fifty postcards that were ordered from each provider were pulled in a consistent pattern for measurement using X-Rite 530 (Series 001982) spectrodensitometer, Observer Angle: 2° D50. Nine color patches were measured in the vector artwork on each vector-only postcard with three readings taken on each color patch to confirm consistency in the values read. There were a total of 7200 measurements taken across all the samples. Then, the average of the three measurements for each color patch were compared to original L*a*b* values to calculate ΔE values for each color patch on each card.

100lb glossy standard paper substrate was specified in each order, however we found there were differences in the papers. In order to determine if optical brighteners or other stock-related issues were significantly affecting the measurements, each stock was measured for paper reflectance. Based on those measurements, it was determined that the differences between the paper stocks was minimal between the printers.

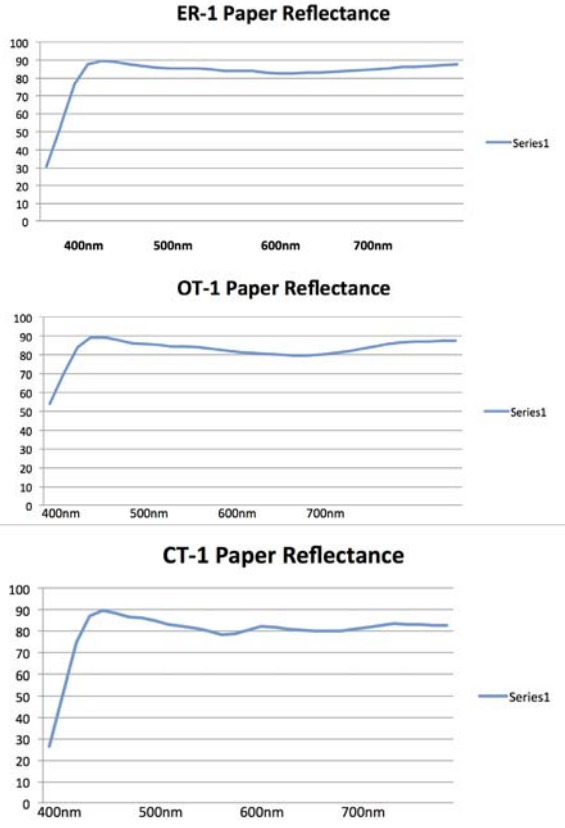


Figure 18: *Sample of paper reflectance graphs from three unique print providers*

Visual Check Measurements

The visual check was completed with forty-eight participants, all of which were Graphic Communications students, at Clemson University. Participants were given a set of the GRACoL raster images that were printed by the print providers, ten prints in all. Participants were also given a target that was considered the best color match to the file.

Working in a D-50 light booth, participants compared printed raster images with a color-managed raster target and ordered them sequentially from closest visual match to the furthest visual match to the target image. Finally, we asked each participant at what point in the order would not be happy to pay for the sample because the color match was too different from the target product.

Participants ranged in age from eighteen to thirty-one. Eight participants were male and forty were female. All of the participants identified themselves as having little to no background in color.

Preliminary Analyses

We compared 9 colors x 10 print providers x 2 color spaces. The nine colors were broken down into sets of three:

1. Three skintones
2. Three neutrals
3. Three saturated colors

The table below, figure 19, shows the mean ΔE and standard deviation ΔE for each of the color patches in both color spaces for one print provider.

Printer	ColorSpace	Color	Mean	N
TT	AdobeRGB	Gray8	3.13314269	10
		Gray6.5	2.50843202	10
		Gray5	1.90082606	10
		purple	5.37600592	10
		green	10.6863497	10
		red	8.65582571	10
		YellowOrange	8.82912411	10
		DarkSkin	4.08800147	10
		LightSkin	3.89766572	10
		Total	5.45281927	90
	GRACoL CMYK	Gray8	5.50977419	10
		Gray6.5	4.91972857	10
		Gray5	1.79594059	10
		purple	3.65993253	10
		green	9.99172657	10
		red	7.65225950	10
		YellowOrange	5.57612462	10
		DarkSkin	.707757110	10
		LightSkin	4.75635367	10
		Total	4.95217748	90

Figure 19: *Chart showing an example print provider, coded as TT, mean ΔE values for each color patch measured*

In order to visualize how each company performed, we combined the data for all the colors into a single value, grand mean of ΔE, to compare across print providers and color spaces, see figure 20. Along the x-axis each print provider is listed by their code. Along the Y-axis, the grand mean ΔE values- combination of all ΔE values for all colors within a single color space- RGB or CMYK- are listed. Differentiation between the color spaces of the originating file are depicted by the lines- grand mean values of the AdobeRGB file are depicted in blue and the grand mean values of the GRACoL CMYK file depicted in green.

We chose to use ΔE 76 in order to show the difference between the LAB colors on the submitted file and the LAB readings on the received prints without factoring in the perceptual differences. The grand mean ΔE values were calculated using the means of all nine spot colors to get an absolute difference between the original files' ΔE values and the printed files received from each print provider. Because the ΔE 76 model does not accommodate for how the human observer perceives color, the mathematical differences between the means allows us to rank the overall color accuracy for the nine spot colors and use the grand mean ΔE to rank printers from overall closest match of the submitted LAB values to the farthest match.

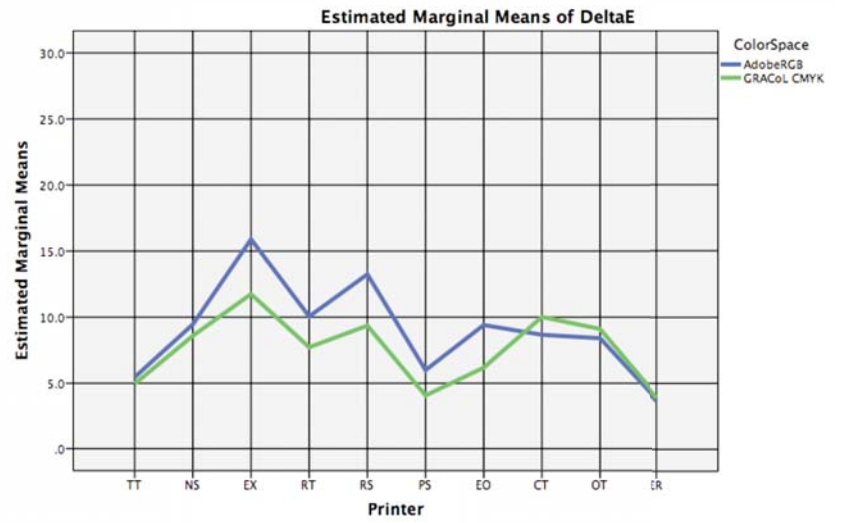


Figure 20: *This chart shows the grand mean ΔE values for each print provider by combining the ΔE values for all the measured colors within each color space in order to visualize the overall color accuracy for each print provider.*

In the following two graphs, figure 21 and 22, each colored line represents a print provider. Across the bottom of the graph are the measured colors- 3 gray tones, 3 saturated colors, and 3 skin-tones. The top graph, figure 21, shows the values based on the Adobe RGB color space file and the bottom graph, figure 22, shows the values measured on the CMYK GRACoL color space files.

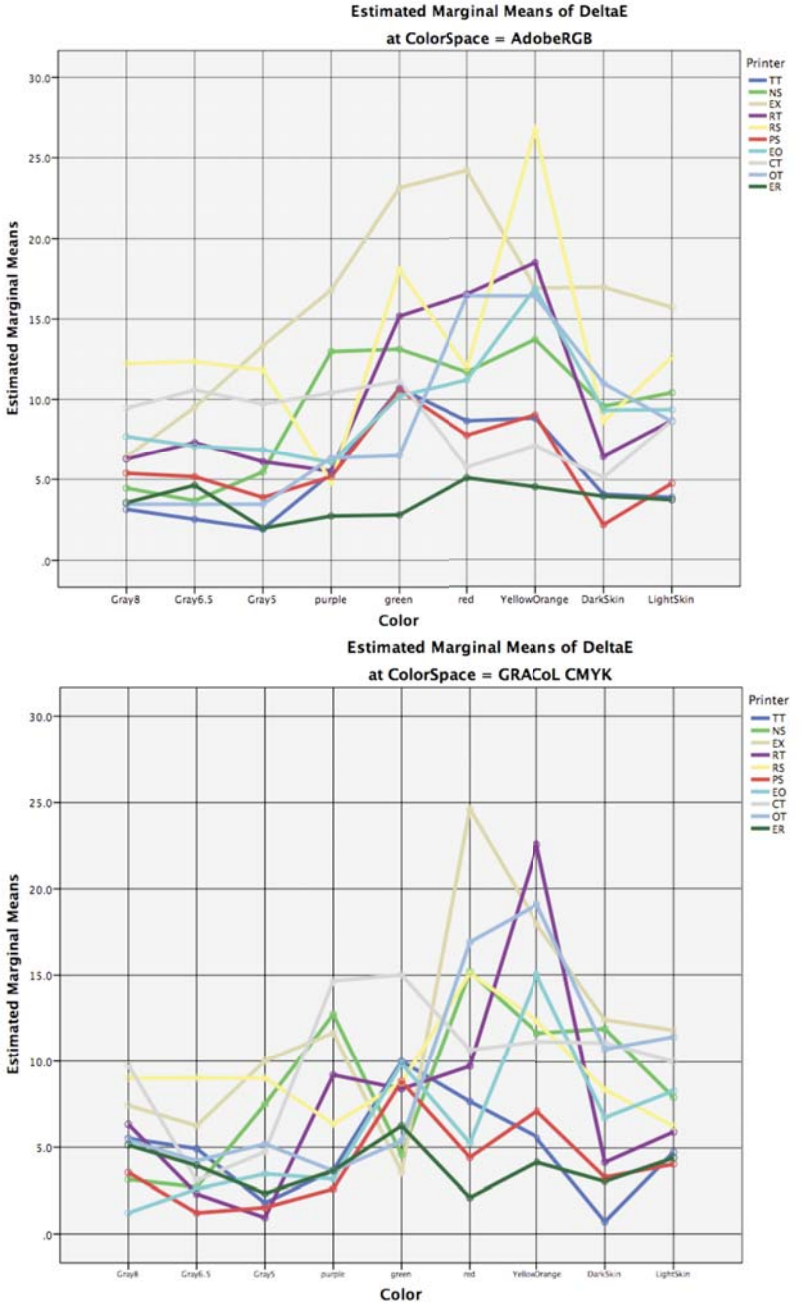


Figure 21,22: *Graphs showing the mean ΔE for each company for each of the nine measured color patches. The top graph shows the AdobeRGB file readings and the bottom graph shows the GRACoL CMYK readings*

Statistical Analysis

We decided to conduct a 3 x 3 x 2 analysis of variance: 3 colors x 3 print providers x 2 color spaces. This model gave us a clearer depiction of possible interactions between the variables.

We chose the colors light skin, gray 6.5 and green to be representative of the color groupings- skin tones, grays, and saturated colors. The statistical method used was a multifactor analysis of variance conducted on SPSS software using "General Linear Model."

We chose three representative print providers to characterize the three levels of print providers:

1. One print provider from the top performing group that had the lowest grand mean ΔE values
2. One print provider from the "mid-range printers" who were moderately off on their grand mean ΔE values
3. One print provider from the group of printers who were the farthest off, on average, on the grand mean ΔE values

Print provider ER was representative of the highest performing print providers. ER had grand mean ΔE values for RGB color space and CMYK color space of 3.66 and 3.90, respectively. Print provider NS was representative of the mid-level print providers. NS had grand mean ΔE values for RGB color space and CMYK color space of 9.45 and 8.59, respectively. Print provider EX was representative of the lowest performing print providers. EX had grand mean ΔE values for RGB color space and CMYK color space of 15.89 and 11.74, respectively.

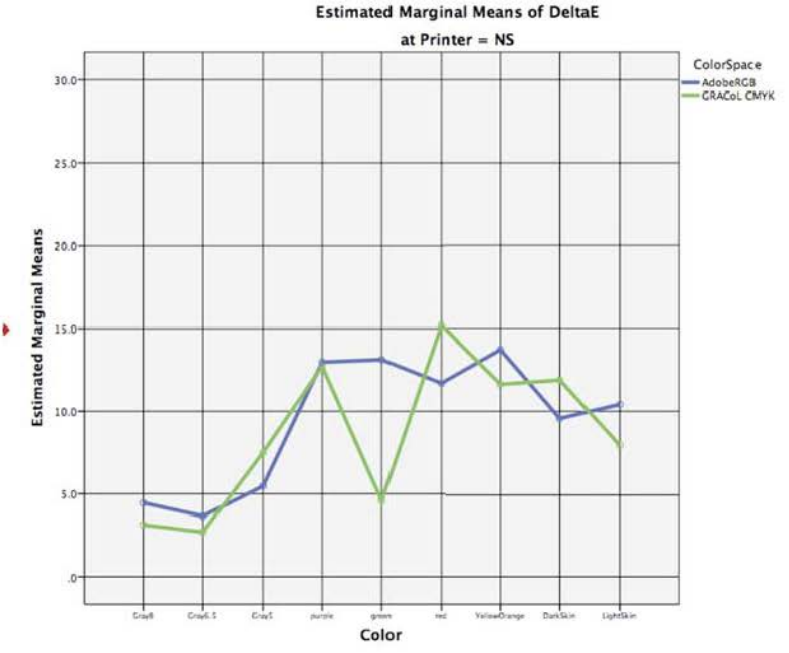
We again included the two color spaces- AdobeRGB and GRACoL CMYK- for the analysis to explore this variable for interactions.

Results

ΔE values by printer color, and color space

The graphs, figures 23-25, below show the mean ΔE values for each measured color. Color is listed along the y-axis and ΔE is listed along the x-axis. The blue line represents AdobeRGB color space and the green line represents the GRACoL CMYK color space. The top graph, figure 23, is for print provider ER, the middle, figure 24, is print provider NS and the bottom graph, figure 25, is print provider EX.


Estimated Marginal Means of DeltaE
at Printer = ER
ColorSpace
AdobeRGB
GRACoL CMYK
Estimated Marginal Means
30.0
25.0
20.0
15.0
10.0
5.0
.0
Gray8
Gray6.5
Gray5
purple
green
red
YellowOrange
DarkSkin
LightSkin
Color


Estimated Marginal Means of DeltaE
at Printer = NS
ColorSpace
AdobeRGB
GRACoL CMYK
Estimated Marginal Means
30.0
25.0
20.0
15.0
10.0
5.0
.0
Gray8
Gray6.5
Gray5
purple
green
red
YellowOrange
DarkSkin
LightSkin
Color

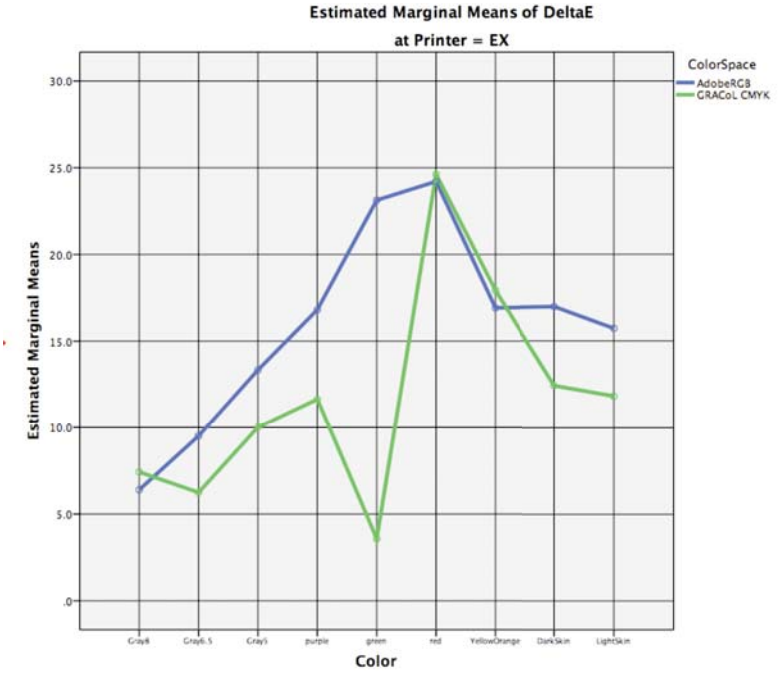
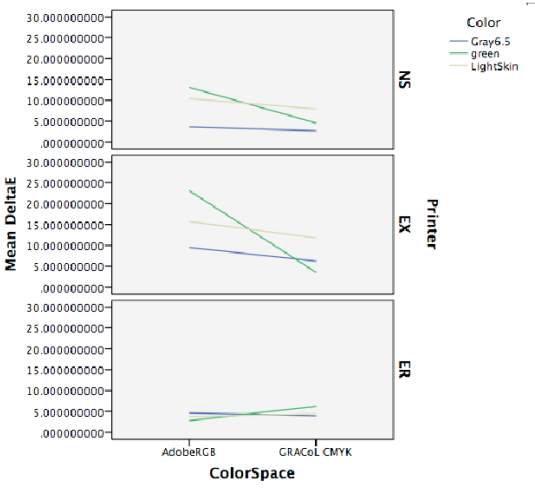


Figure 23, 24, 25: *Results of the multifactor analysis for the three representative print providers*

Results of the modified (3 x 3 x 2) analysis were as follows. There was a main effect for color space with GRACoL CMYK more accurate (lower ΔE values) than the RGB color space. Second, and as would be expected, there was a main effect for printer with findings consistent with the original analysis. And finally, there was a main effect for color with gray tones having the lowest ΔE values.

In addition, there were a number of interactions. Specifically, color and color space mattered more for some printers than for others. As can be seen in figure 26 below, the print provider you choose matters, the color space of the file you send matters, and the colors within your artwork matter in regards to color consistency.



Color	ColorSpace	Mean
Gray6.5	AdobeRGB	3.660
	GRACoL CMYK	2.702
green	AdobeRGB	13.124
	GRACoL CMYK	4.585
LightSkin	AdobeRGB	10.417
	GRACoL CMYK	7.935
Gray6.5	AdobeRGB	9.508
	GRACoL CMYK	6.242
green	AdobeRGB	23.130
	GRACoL CMYK	3.573
LightSkin	AdobeRGB	15.727
	GRACoL CMYK	11.811
Gray6.5	AdobeRGB	4.624
	GRACoL CMYK	3.948
green	AdobeRGB	2.782
	GRACoL CMYK	6.242
LightSkin	AdobeRGB	3.751
	GRACoL CMYK	4.424

Figure 26: *Image showing the graph depicting main effects and the chart listing the grand mean ΔE values for each printer in both the GRACoL CMYK and the AdobeRGB color space.*

Visual Comparisons

For the visual comparison, each participant ordered the provided samples, the printed photograph from each print provider, sequentially from closest visual match to the furthest visual match from a specified target image. An ordering board was provided that allowed data to be quickly gathered by flipping the board over to reveal a color-coded system for identifying the print provider who supplied each printed sample. Generalizations could then be made about how participants ordered the samples in comparison to the grand mean ΔE values from each print provider. Results are shown below in figures 27 and 28.

Code	GRACoL Mean	Ranking
ER	3.8979	1
PS	4.0703	2
TT	4.9522	3
EO	6.1819	4
RT	7.7247	5
NS	8.589	6
OT	9.1057	7
RS	9.3603	8
CT	10.015	9
EX	11.7425	10

		1	2	3	4	5	6	7	8	9	10
1	ER	23	8	2	1	3	6	1	3	0	0
2	PS	1	4	11	6	6	3	3	4	2	0
3	TT	7	9	8	7	3	9	3	1	0	0
4	EO	3	3	4	5	3	3	11	3	1	0
5	RT	5	6	6	6	9	4	2	4	0	0
6	NS	3	6	10	9	8	5	3	1	2	1
7	OT	1	3	4	7	5	8	8	6	2	4
8	RS	0	4	1	3	4	2	15	6	13	0
9	CT	1	0	0	0	1	1	2	6	0	28
10	EX	0	1	1	1	1	4	6	4	17	13
		On average people are satisfied with the first 5.79 output samples									

Figure 27, 28: *The top chart shows the grand mean ΔE of the measured GRACoL color patches for each printer in order from lowest ΔE to highest and the associated print provider code. The second chart shows the aggregated results from the visual comparison done by participants.*

In figure 28, it can be seen that although participants did not rank the samples in the same order, the trend shows that they did tend to keep the samples from the 5 print providers, those with the lowest grand mean ΔE values, in the top 5 positions and the samples with the highest grand mean ΔE values in the last 5 positions. There was one notable exception in the participants' rankings. That was the print provider EO (fourth row, figure 28), which seemed to have a different distribution in ranking order than anticipated. Although we are unsure of the exact cause of the difference in visual ranking for this sample, we did notice that, this print provider had below a ΔE value of 10 for all color patches except yellow-orange which had a ΔE value of 15.01, so perhaps the difference in that particular tone was especially noticeable to our participants.

We also examined the relationship between the grand mean ΔEof each print provider and how often the sample from that print provider was rated in the top five printers for visual match by the participants. The measure of association used was Spearman rank order correlation (n=10). We obtained a rank order correlation coefficient of

.89, p=.01, see figure 29, showing that grand mean ΔE was a strong predictor of consumer satisfaction with color accuracy.

Correlations

			meandeltaeGR	top5asrank
Spearman's rho	meandeltaeGR	Correlation Coefficient	1.000	.888**
		Sig. (2-tailed)	.	.001
		N	10	10
	top5asrank	Correlation Coefficient	.888**	1.000
		Sig. (2-tailed)	.001	.
		N	10	10

**. Correlation is significant at the 0.01 level (2-tailed).

Figure 29: *Showing the Spearman rank order correlation between the grand mean ΔE values and their rank order by participants during the visual check.*

Conclusions

General Conclusions

In the GRACoL CMYK color space, overall mean ΔE values are slightly smaller than in the RGB color space. Gray tones measure lower ΔE values in both color spaces- RGB and CMYK- than any other color grouping. Skintones are slightly closer to their intended values in the GRACoL color space than in the RGB color space. All print providers attained the lowest ΔE values, and therefore the closest visual match, in the gray tones regardless of the provided color space. On the other hand, saturated tones- yellow/orange, red, and green- had the highest ΔE values across all the print providers.

Specific Findings

With respect to color, the saturated tones had the broadest range in their ΔE means. From the RGB color space, yellow/orange ΔE means range from 26.68 to 4.56 between print providers, red ΔE means range from 24.21 to 5.12 between print providers, and green ΔE means range from 23.13 to 2.78 between print providers. In the CMYK color space files, yellow/orange ΔE means range from 22.56 to 4.18 between print providers, red ΔE means range from 24.62 to 2.10 between print providers, and green ΔE means range from 15.02 to 3.57 between print providers. It can be concluded that the saturated tones were the most difficult for print providers to accurately reproduce and that there was a vast difference between print providers color accuracy within these tones.

With regard to print providers, both the mid-level print provider and the lowest performing print provider have similar results on the three colors- light skintone,

gray and green. In figure 26, gray, represented by the blue line, is closer to accurate (smaller ΔE value) than the other two colors. As for color spacing, both gray and light skintone perform slightly better (but not statistically better) in the GRACoL color space than in the RGB color space. For print providers NS and EX, green is the most difficult color to match with ΔE values of 23.13 and 13 respectively in the RGB color space and 3.57 and 4.59 respectively in the GRACoL color space. Print provider ER, representative of the highest performing print providers in the study, measured less than a 5 ΔE for all three colors in both color spaces only going above a 5 ΔE value for the green tone in the GRACoL color space. Again, even in the highest performing print providers, the saturated colors are the most difficult to recreate with accuracy.

We also looked at the discernible pattern between cost, speed and quality. Cost per order of postcards, ranged in price from $37.44 to $163.97 per fifty post cards. Delivery speed ranged from same day shipping to eight days from the order being placed until it was shipped from the printing facility. Although the first ranked printer in ΔE color accuracy also was the slowest to ship and the tenth ranked printer in ΔE color accuracy provided same day shipping, neither cost nor speed had a consistent discernible pattern with color accuracy, see figure 30.

Code	GRACoL Ranking	Cost per 50-CMYK	Shipped # of days after ordering
ER	1	$64.05	8
PS	2	$57.77	2
TT	3	$116.99	1
EO	4	$72.50	1
RT	5	$163.97	6
NS	6	$161.40	2
OT	7	$140.86	1
RS	8	$37.85	1
CT	9	$68.90	3
EX	10	$159.43	same day

Figure 30: *Comparison of print provider ranking based on grand mean ΔE color accuracy with the factors of cost and speed*

Finally, in regards to the visual comparison, although participants did not rank the samples in the exact same order, the trend shows that they tended to keep the samples from the 5 print providers with the lowest mean ΔE values in the top 5 positions of color match; and the samples with the highest mean ΔE values in the last 5 positions.

Additionally, the participants were, in general, satisfied with the first six print provider's samples. Based on their appraisal of which samples were acceptable, the participants, claimed that they were satisfied, on average, with samples that had an 8.59 grand mean ΔE value or below.

There are many directions that future research could take to further explore how Web2Print systems process and handle color and the consumer's tolerance for variation between initial input and the printed output. Suggestions for further research include using different photographs and vector images to see how visual perceptions change when ΔE values for different predominate colors exist in the original artwork. Color does produce an emotional response for participants, so photographs with different predominate colors and sensitivity to variance could affect participant ordering of files for the visual check aspect. Future studies might also consider using an eye-tracking program to show which areas of the photograph and which colors participants' factor most heavily when determining color accuracy rankings.

This study could be also be repeated with the knowledge and participation of the selected print providers. Then researchers could determine both the affect of different RIPs on the provided files and how different print processes affect color accuracy and consistency within the final printed piece. Another advantage of working openly with the print providers could be to look at the standards and certifications employed to determine how those standardized processes affect the ΔE accuracy of the color patches on the end product.

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