A Comparison of App-based Color Measurement Devices to Spectrophotometers

Dina Vees and Malcolm Keif

Keywords: color management, color measurement, color measurement devices, colorimeter, spectrophotometer

Abstract

Maintaining color consistency across various print methods and substrates is a daily challenge for the printing professional. Accurately reproducing brand colors demanded by customers is of the utmost importance. It is common practice to manage color accuracy by measuring color attributes throughout the print workflow using colorimeters or spectrophotometers.

This empirical research study looks at three new low-cost app-based measurement devices to determine their intermodel agreement with two professional spectrophotometers. An experimental study was conducted to look at the five measurement devices to determine standard deviation, precision or repeatability of measurements, consistency of L*a*b* readings, and Delta E 2000 values to understand the performance of low-cost devices.

The instruments studied in this research were the Nix Mini, Nix Pro 2, Variable Spectro 1™, X-Rite 530 and the Techkon SpectroDens. The X-Rite and Techkon are spectrophotometers with built-in processing and are considered professional instruments, while the Nix and Variable devices are app-based and often considered consumer devices, which sell for considerably less than the other professional models. We grouped these three and called them "low-cost" instruments for the purpose of this study.

Seven Pantone® colors were selected and twenty repeated measurements were taken for each device. All devices were calibrated and measurements were taken with little to no movement between twenty readings. In other words, all devices measured the approximate same spot, though aperture sizes varied among instruments. CIELAB measurements were captured using D50 illuminant, 2°

California Polytechnic State University

Observer and 45°/0° geometry for all instruments with the ability to set these paramenters. The SpectroDens, which is ISO 13655:2009 compatible, was set to measurement mode M0 to try to maintain consistency with the other devices. A white backing was used during all measurements.

Three hypotheses formed the basis of the research:

- H_1 – *Low-cost instruments have greater measurement variation across repeated measurements than professional spectrophotometers.*
- H_2 – *Low-cost instruments produce statistically different L*a*b* readings than professional spectrophotometers.*
- H_3 – *Low-cost instruments have greater calculated Delta E 2000 values relative to professional spectrophotometers.*

While all measurements were taken from a new Pantone® guide, we used Pantone's digital L*a*b* values from Pantone's website as the reference for calculating Delta E 2000 (ΔE_{00}). Since the production of Pantone® guides are subject to printing variation too, we did not consider a particular ΔE_{00} to be "correct", but rather looked at trends and other evidence of variation in our study.

The low-cost instruments do not measure to the same level of significant figures as the professional devices resulting in precision differences. This made direct comparisons somewhat challenging during analysis, particularly for H1 *Low-cost instruments produce statistically different L*a*b* readings than professional spectrophotometers*. Comparing standard deviations of the various measurements proved futile since the Nix Mini reported all readings to whole numbers and therefore had very little deviation of readings. We were not able to confirm H1 and instead rejected that hypothesis. Analysis of variance (ANOVA) gave us a better understanding of the performance of these devices and allowed us to analyze the other two hypotheses effectively despite the difference in precision among the devices.

Hypothesis H2, *Low-cost instruments produce statistically different L*a*b* readings than professional spectrophotometers* was confirmed using analysis of variance and post-hoc analysis using Tukey's HSD at a 95% confidence level. We also were able to confirm H3 that *Low-cost instruments have greater calculated ΔE_{00} values relative to professional spectrophotometers* by using Tukey's HSD at a 95% confidence level and comparing the mean range of Δa^*_{00}, Δb^*_{00}, ΔL, ΔC, ΔH readings across all 7 colors.

The three low-cost, app-based devices are small, inexpensive and easy to use, off-loading all color computations to a mobile app, but do not provide the precision or consistency necessary to compare to professional spectrophotometers used in industry to meet critical color reproduction standards.

Introduction

Color accuracy is a significant factor in the printing industry for meeting customer requirements. Matching brand colors and ensuring color consistency across substrates and press runs remains a challenge. New, inexpensive color measurement devices were recently introduced for a multitude of applications, making these devices available for common use. However, little has been published as to whether these low-cost devices measure comparably to the industry-standard spectrophotometers used in print.

This research compares intermodel agreement of three new low-cost products to common professional spectrophotometers. “Intermodel agreement” refers to the comparison of measurements from different models or manufacturers of instruments (Sharma, 2018). Two of the devices studied are colorimeters. A colorimeter sees color like the human eye, quantifying the tristimulus red, green, and blue components of each measurement and using that data to determine a color’s location in CIELAB color space (X-Rite Color, 2015). A third new device is a spectrophotometer. Spectrophotometers filter light into narrow bands of color that pass through the instrument optics and onto a receiver where they are analyzed (X-Rite Color, 2015). Spectrophotometers typically measure spectral reflectance at 10 nm increments.

Five instruments were evaluated in this study, focusing on intermodel agreement between the instruments:

- Low-cost, app-based
    - Nix Mini
    - Nix Pro 2
    - Variable Spectro 1™
- Professional
    - X-Rite 530
    - Techkon SpectroDens

All three low-cost instruments incorporate mobile applications with blue-tooth connectivity. These app-based devices allow the manufacturer to save costs of onboard processing in their instruments.

Purpose of the study

The purpose of this research is to determine if new, low-cost color measurement devices provide accurate measurements for graphic communication applications. If these less expensive devices offer acceptable intermodel agreement for basic color measurement with professional instruments, the issue then becomes merely a matter of evaluating feature sets. Professional spectrophotometers typically offer more measurement features, including density, tone value increase, hue error, etc.

However, if these instruments measure color differently or to a looser tolerance than professional instruments, users should be careful as to their reliance on these instruments for critical evaluation of color.

Three hypotheses were developed in this research:

- H1 – Low-cost instruments have greater measurement variation across repeated measurements than professional spectrophotometers.
- H2 – Low-cost instruments produce statistically different L*a*b* readings than professional spectrophotometers.
- H3 – Low-cost instruments have greater calculated Delta E 2000 values relative to professional spectrophotometers.

Review of Related Literature

Color measurement has been an important subject for decades. Ensuring the client's brand color is produced accurately and repeatedly is a primary standard for quality printing. There are many ways print is produced. Examples of different print methods include sheetfed offset, web offset, gravure, screen, flexography, and digital. Each of these print methods has its own challenges for reproducing color. Occasionally a piece is printed in one method the first time and a different method the second time. Maintaining color consistency with the original print run and the designer's intent is essential. When the same piece is printed multiple times months apart, this can also bring challenges in reproducing the piece with the same color as the original print run.

Maintaining color consistency and repeatability with these variables present can be challenging. Maintaining color accuracy is achieved through process control and characterization by measuring color "by the numbers" and applying a profile that reflects the characterization of the press. With spot colors, ink drawdowns are used to create a reference for ink formulation. This measuring of drawdowns and press sheets are typically done with a spectrophotometer.

Colorimeter vs Spectrophotometer

Spectrophotometers use multiple sensors to measure the spectral reflectance of the color. It splits light into its component colors and measures how much there is at each wavelength (Sharma, 2018). These instruments have the ability to specify the CIE Illuminant and the standard observer angle.

"An illuminant is a mathematical representation of a theoretical light source, used for calculating tristimulus values from a spectrophotometric measurement." (Understanding Illuminants, n.d.). The 2009 revision of ISO 13655 defined four different modes for measuring color, as shown in Table 1. The standard illuminant used in M0 uses a mathematical representation of tungsten halogen (incandescent), M1 uses the D50 representation of daylight, M2 is used when optical brighteners in the substrate need to be eliminated from the reading, and M3 is used to measure color on press sheets with wet ink. M0 is used by the majority of measuring devices today (Sharma, Leung, & Adams II, 2017). To maintain consistency with the colorimeters and spectrophotometers, M0 was used in this experiment for the Techkon SpectroDens, which was the only device of the five we looked at that supports these four measurement conditions.

Measurement Mode	Mode	Light Source
M0	Legacy	Tungsten commonly used
M1	UV-included	D50
M2	UV-excluded	Removes all UV light below 400nm
M3	Polarizing	Wet press sheet readings

Table 1: *ISO 13655:2009 new measurement modes*

The standard observer angle is used to correlate instrument color measurement to human visual assessments (Understanding Standard Observers in Color Management). ISO 13655:2017 prefers the smaller 2˚ observer angle because it more closely matches how printed material is viewed (International Organization for Standardization, 2017). The instruments in this experiment were set to the 2˚ observer angle to maintain consistency between the spectrophotometers and colorimeters.

A calibration tile is included with spectrophotometers to ensure accurate and repeatable color readings by resetting the instrument's zero-point. All three spectrophotometers used in this experiment were calibrated prior to measuring color data.

Colorimeters are "filter-based instruments that use at least three filters behind each of which is a photodetector photocell, usually some sort of photodiode. The important aspect of a colorimeter is that the system has a response equal to that of the CIE standard observer, so that the instrument directly measures XYZ." (Sharma, 2018, p. 101). Software is used to determine other color metrics, such as L*a*b* and LCH. Colorimeters cannot record spectral data; they only provide XYZ values. (Sharma, 2018).

The Nix devices are both colorimeters that have a tristimulus sensor and the 45˚/0 measurement geometry. This measurement geometry is the standard for most devices other than sphere spectrophotometers used for measuring on metallic substrates, which use an 8° measurement geometry. The measurement geometry refers to the angle of incident light (45˚) and the measured light (0°) (Sharma, 2018). This measurement is the same for both the colorimeters and spectrophotometers.

A tristimulus sensor measures the light reflected from the color swatch to have the same sensitivity as the human eye (Precise Color Communication, n.d.).

The aperture of a device is the diameter of the optic that reads the color swatch. Light travels through the optic to capture the values. The colorimeters used in this experiment both have an aperture of 14mm—the largest of all the devices. The professional spectrophotometers have an aperture of 3mm (Techkon) and 3.4mm (X-Rite), as shown in Table 2. A larger aperture reads a larger area of the color sample. Typically, a smaller aperture is used in professional applications due to the size of the color bar patch. This is a variable that should be noted when assessing the data collected.

Device	**Type**	**Aperture Size**	**Measurement Significant Figures (in decimal places)**	**Calibration with supplied white tile**	**App based**
Nix mini	Colorimeter	14mm	0 (whole numbers only)		x
Nix Pro 2	Colorimeter	14mm	1		x
Spectro 1	Spectrophotometer	8mm	1	x	x
Techkon SpectroDens	Spectrophotometer	3mm	2	x	
X-Rite 530	Spectrophotometer	3.4mm	2	x	

Table 2: *Measurement parameters for the five instruments*

Delta E

Delta E (ΔE) is a formula developed by color scientists to better correlate how a human sees color differences. When comparing two color samples, a large ΔE means the human eye will see the samples as distinctly different, and a small ΔE would suggest the colors look visually similar. The numeric measure from the color samples being compared allows us to easily determine if the color is within the specification needed. Calculating ΔE requires measuring the color samples using the L*a*b* color space.

This experiment used the CIE Delta E 2000 equation. For many colors sampled, this equation will give a more realistic value of the perceived color difference. This method is regarded as a “more logical and representative tolerancing system” (Sharma, 2018, p. 91). The CIE Delta E 2000 equation is the preferred formula to use today.

Equation 1: Delta E 2000 formula (Lindbloom, n.d.)

$$\Delta E\ (\text{CIE } 2000) = \sqrt{\left(\frac{\Delta L'}{K_L S_L}\right)^2 + \left(\frac{\Delta C'}{K_C S_C}\right)^2 + \left(\frac{\Delta H'}{K_H S_H}\right)^2 + R_T\left(\frac{\Delta C'}{K_C S_C}\right)\left(\frac{\Delta H'}{K_H S_H}\right)}$$

Where

$$\bar{L}' = (L_1 + L_2)/2$$

$$C_1 = \sqrt{a_1^2 + b_1^2}$$

$$C_2 = \sqrt{a_2^2 + b_2^2}$$

$$\bar{C}' = (C_1 + C_2)/2$$

$$G = \frac{1}{2}\left(1 - \sqrt{\frac{\bar{C}^7}{\bar{C}^7 + 25^7}}\right.$$

$$a_1' = a_1(1 + G)$$

$$a_2' = a_2(1 + G)$$

$$C_1' = \sqrt{a_1'^2 + b_1^2}$$

$$C_2' = \sqrt{a_2'^2 + b_2^2}$$

$$\bar{C}' = (C_1' + C_2')/2$$

$$h_1' = \begin{cases} \arctan(b_1/a_1') & \text{if } \arctan(b_1/a_1') \geq 0 \\ \arctan(b_1/a_1') + 360° & \textit{otherwise} \end{cases}$$

$$h_2' = \begin{cases} \arctan(b_2/a_2') & \text{if } \arctan(b_2/a_2') \geq 0 \\ \arctan(b_2/a_2') + 360° & \textit{otherwise} \end{cases}$$

$$H' = \begin{cases} (h_1' + h_2' + 360°)/2 & \text{if } |h_1' + h_2'| > 180° \\ (h_1' + h_2')/2 & \textit{otherwise} \end{cases}$$

$$T = 1 - 0.17\cos(\bar{H}' - 30°) + 0.24\cos(2\bar{H}') + 0.32\cos(3\bar{H}' + 6°) - 0.20\cos(4\bar{H}' - 63°)$$

$$\Delta h' = \begin{cases} h_2' + h_1' & \text{if } |h_2' + h_1'| \leq 180° \\ h_2' + h_1' + 360° & \text{else if } |h_2' + h_1'| > 180° \text{ and } h_2' \leq h_1' \\ h_2' + h_1' - 360° & \textit{otherwise} \end{cases}$$

$$\Delta L' = L_2 - L_1$$

$$\Delta C' = C_2 - C_1$$

$$\Delta H' = 2\sqrt{C_1'C_2'}\sin(\Delta h'/2)$$

$$S_L = 1 + \frac{0.015(\bar{L}' - 50)^2}{\sqrt{20 + \bar{L}' - 50)^2}}$$

$$S_C = 1 + 0.045\bar{C}'$$

$$S_H = 1 + 0.015\bar{C}'T$$

$$\Delta\theta = 30\ \exp\left\{-\left(\frac{\bar{H}'-275^\circ}{25}\right)^2\right\}$$

$$R_C = 2\sqrt{\frac{\bar{C}'^7}{\bar{C}'^7 + 25^7}}$$

$$R_T = -R_C \sin(2\Delta\theta)$$

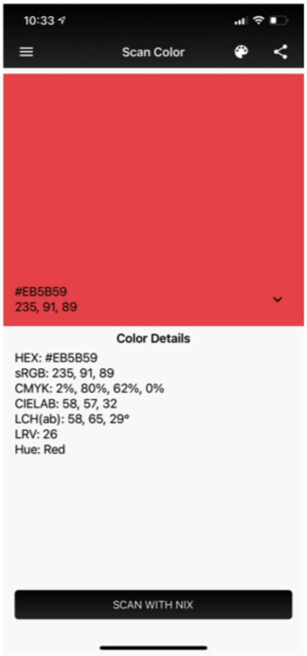
$$K_L = 1 \text{ default}$$

$$K_C = 1 \text{ default}$$

$$K_H = 1 \text{ default}$$

Research Methods

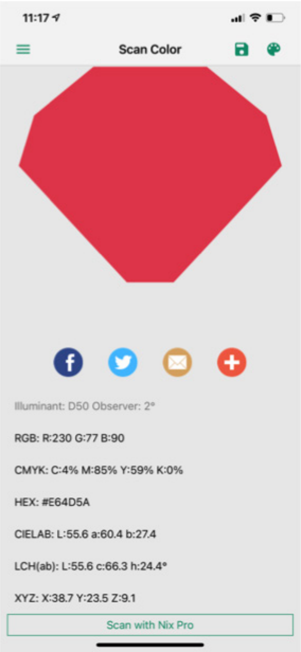
Data were collected using five instruments. A new Pantone® solid uncoated Formula Guide served as the test vehicle for all measurements. All samples were measured with a white backing. A range of "ROYGBIV" spot colors were selected for measurement, representing a broad range of brand colors. Care was taken to measure the center of each swatch for consistent readings for all devices. All devices except the X-Rite 530 were placed and not moved for the duration of the twenty measurements. The X-Rite's clamshell design requires the device to be opened and closed for each reading, resulting in potential minimal target movement. Also, the design of the Techkon SpectroDens involves a moving measurement optic.



#EB5B59
235, 91, 89

Color Details
HEX: #EB5B59
sRGB: 235, 91, 89
CMYK: 2%, 80%, 62%, 0%
CIELAB: 58, 57, 32
LCH(ab): 58, 65, 29°
LRV: 26
Hue: Red

Figure 1: *Nix Mini color sample*



Illuminant: D50 Observer: 2°
RGB: R:230 G:77 B:90
CMYK: C:4% M:85% Y:59% K:0%
HEX: #E64D5A
CIELAB: L:55.6 a:60.4 b:27.4
LCH(ab): L:55.6 c:66.3 h:24.4°
XYZ: X:38.7 Y:23.5 Z:9.1

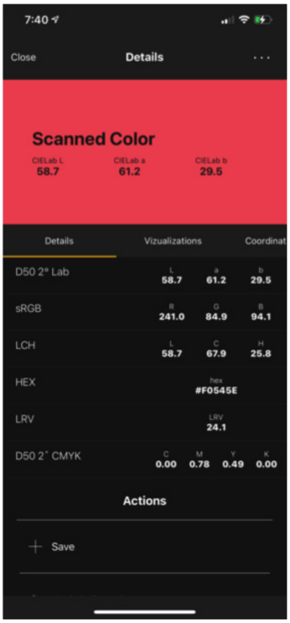
Figure 2: *Nix Pro color sample*

Prior to measurement, all spectrophotometers were calibrated using their supplied white tiles; the colorimeters relied on factory calibration. As noted in Table 2, the aperture size for each instrument was not the same, implying that any imperfections in the swatch book would be sampled differently.

The Nix Mini did not have any settings that could be adjusted—just connect and scan color values. The Nix Digital app V 1.7.1 was used to read color data. An example of the color reading is shown in Figure 1. The Nix Pro device uses the NixProColorSensor App. Version 2.6.4 was used for this experiment. The D50 Illuminant and 2˚ Observer were set prior to scanning color swatches. An example of the resulting scan is shown in Figure 2.

The Spectro 1 has the widest available settings of the three app-based devices. As shown in Figure 5, the CIE Lab color format, D50 Illuminant, 2˚ Observer, Delta E 2000 Formula, CMYK ICC Profile, and Rendering intent were all defined prior to reading color swatches. The Spectro app v 8.10.31 was used for reading color data in this experiment.

The X-Rite and Techkon measurement parameters were set to CIELAB, D50 illuminant, 2˚ observer angle, 45°/0° geometry. In the case of the Techkon SpectroDens, which offers the four measurement modes associated with how the illuminant reacts with the substrate, we used the M0 mode to better align with the legacy devices. All measurements were made within a one-week period.



Scanned Color

CIELab L 58.7 · CIELab a 61.2 · CIELab b 29.5

D50 2° Lab	L 58.7	a 61.2	b 29.5	
sRGB	R 241.0	G 84.9	B 94.1	
LCH	L 58.7	C 67.9	H 25.8	
HEX	hex #F0545E			
LRV	LRV 24.1			
D50 2˚ CMYK	C 0.00	M 0.78	Y 0.49	K 0.00

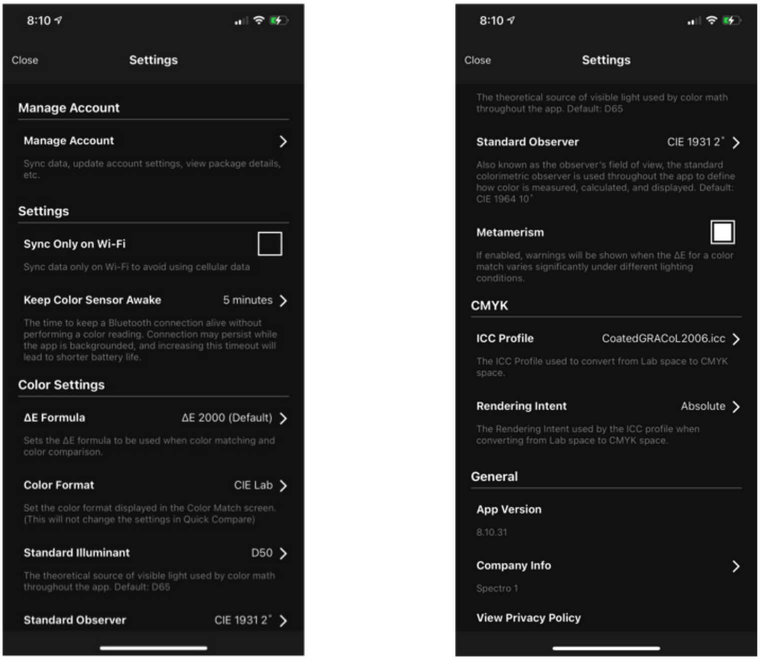
Figure 3: *Spectro 1 color sample*

Figure 4: *Pantone® colors used for measurement*

An experimental study was designed to test three hypotheses:

- H1 – Low-cost instruments have greater measurement variation across repeated measurements than professional spectrophotometers.
- H2 – Low-cost instruments produce statistically different L*a*b* readings than professional spectrophotometers.
- H3 – Low-cost instruments have greater calculated Delta E 2000 values relative to professional spectrophotometers.

L*a*b* values were recorded for all readings. Standard deviation and Delta E 2000 values were computed for each device by color. Delta E 2000 was calculated using the digital L*a*b* reference values from the Pantone® website as the standard. It should be noted, Pantone® books are subject to the same variation that all print manufacturing experiences. Therefore, we did not consider any specific instrument inferior by not reading the digital reference values precisely.



Manage Account

Manage Account
Sync data, update account settings, view package details, etc.

Settings

Sync Only on Wi-Fi ☐
Sync data only on Wi-Fi to avoid using cellular data

Keep Color Sensor Awake: 5 minutes
The time to keep a Bluetooth connection alive without performing a color reading. Connection may persist while the app is backgrounded, and increasing this timeout will lead to shorter battery life.

Color Settings

ΔE Formula: ΔE 2000 (Default)
Sets the ΔE formula to be used when color matching and color comparison.

Color Format: CIE Lab
Set the color format displayed in the Color Match screen. (This will not change the settings in Quick Compare)

Standard Illuminant: D50
The theoretical source of visible light used by color math throughout the app. Default: D65

Standard Observer: CIE 1931 2˚

The theoretical source of visible light used by color math throughout the app. Default: D65

Standard Observer: CIE 1931 2˚
Also known as the observer's field of view, the standard colorimetric observer is used throughout the app to define how color is measured, calculated, and displayed. Default: CIE 1964 10˚

Metamerism ☐
If enabled, warnings will be shown when the ΔE for a color match varies significantly under different lighting conditions.

CMYK

ICC Profile: CoatedGRACoL2006.icc
The ICC Profile used to convert from Lab space to CMYK space.

Rendering Intent: Absolute
The Rendering Intent used by the ICC profile when converting from Lab space to CMYK space.

General

App Version
8.10.31

Company Info
Spectro 1

View Privacy Policy

Figure 5: *Spectro 1 settings*

Analysis of Variance (Anova) and post-hoc analysis using Tukey's HSD (honestly significant difference) were conducted to determine if differences were statistically significant or merely a result of chance. Tukey's HSD conducts significance tests of all combinations of pairs. Tukey's HSD is a t-test that corrects for family-wise error as follows:

Equation 2 - Tukey's HSD formula

$$q_s = \frac{Y_A - Y_B}{\mathrm{SE}}$$

Where Y_A is the larger of the two means, Y_B is the smaller of the two means and *SE* is the standard error of the sum of the means. q_s is then compared to a *q* value from the studentized range distribution to determine if the difference is statistically significant.

Findings

Twenty L*a*b* measurements were collected from sample readings for all instruments. As noted in Table 2, the Nix mini reports measurements to the nearest whole number and the Nix Pro 2 and Spectro 1 measure to one decimal place. The X-Rite 530 and Techkon SpectroDens measure to two decimal places. This adds some complexity in interpreting repeatability. The greater the precision or granularity, the greater the potential deviation across multiple readings. Further, the larger the aperture of the measurement device, the more "averaging" of the measured area. The Nix Mini had a standard deviation of 0 for all readings, with all readings resulting in the same whole number for repeated measurements (Table 3). Similarly, the Nix Pro 2 and Spectro 1 had some measurements with 0 standard deviation, particularly in L*, while other measurements experienced different values across the twenty readings.

The Techkon and X-Rite, instruments with greater significant figures, also had low standard deviations. Both of these instruments have greater precision by reading to two decimal places and also have smaller apertures. While care was taken to minimize variation, the X-Rite's clamshell design may have resulted in minor repositioning of the instrument between readings.

	L*	a*	b*	
Nix Mini	0	0	0	185U
Nix Pro 2	0	0.048936048	0.041039134	
Spectro 1	0.048936048	0.041039134	0.067082039	
Techkon	0.021588252	0.010699238	0.008255779	
X-Rite 530	0.012182818	0.018202082	0.035997076	
	L*	a*	b*	
Nix Mini	0	0	0	021U
Nix Pro 2	0.044426166	0.051041779	0.047016235	
Spectro 1	0.036634755	0	0.050262469	
Techkon	0.009104655	0.014095539	0.036774562	
X-Rite 530	0.014363697	0.014653902	0.028654016	

	L*	a*	b*	
Nix Mini	0	0	0	123U
Nix Pro 2	0	0.030779351	0	
Spectro 1	0	0.044426166	0.064072328	
Techkon	0.009947229	0.009119095	0.006882472	
X-Rite 530	0.011050125	0.011470787	0.023508117	
	L*	a*	b*	
Nix Mini	0	0	0	GreenU
Nix Pro 2	0	0.047016235	0.036634755	
Spectro 1	0	0.036634755	0.036634755	
Techkon	0.005104178	0.009947229	0.004103913	
X-Rite 530	0.005525063	0.029642608	0.012085224	
	L*	a*	b*	
Nix Mini	0	0	0	286U
Nix Pro 2	0	0.044426166	0	
Spectro 1	0	0.02236068	0.050262469	
Techkon	0.015927467	0.00875094	0.00978721	
X-Rite 530	0.009119095	0.00680557	0.02566997	
	L*	a*	b*	
Nix Mini	0	0	0	Reflex Blue U
Nix Pro 2	0	0	0	
Spectro 1	0	0	0.050262469	
Techkon	0.011470787	0.009119095	0.025339796	
X-Rite 530	0.011192102	0.018202082	0.015217718	
	L*	a*	b*	
Nix Mini	0	0	0	Violet Blue U
Nix Pro 2	0.036634755	0.039403446	0.068633274	
Spectro 1	0	0.051298918	0.052314836	
Techkon	0.044042444	0.046009152	0.049510764	
X-Rite 530	0.037752658	0.052261992	0.072349663	

Table 3: *Standard deviation measurements. Note that the Nix Mini measures in whole numbers only, while the Nix Pro 2 and Spectro 1 measure to one decimal point. The professional instruments measure to two decimal places.*

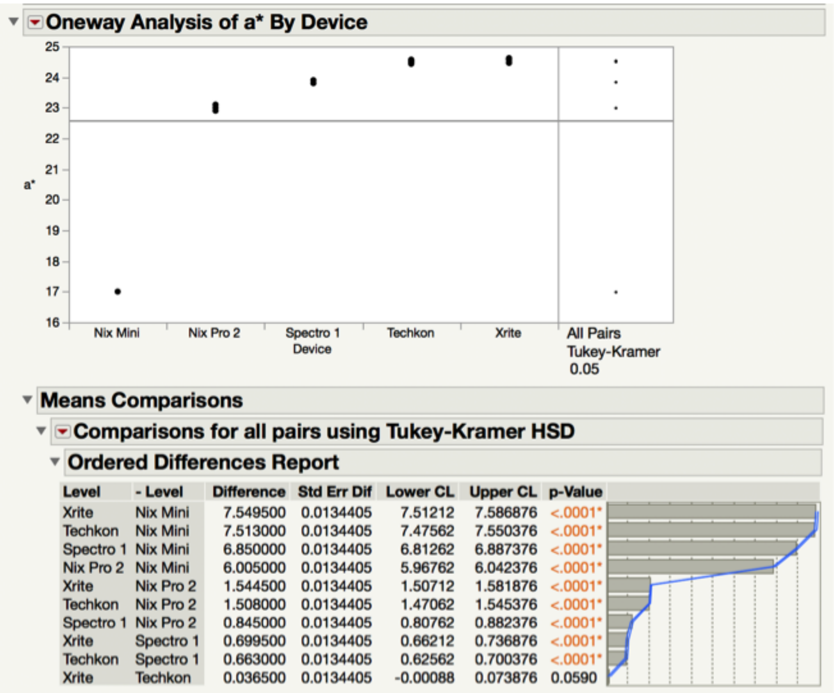
While additional analysis may be necessary, due to the differences in the level of significant figures, hypothesis H_1 is rejected. We cannot conclude that low-cost instruments have greater measurement variation across repeated measurements.

JMP® Pro was used to compare the statistical differences in mean L*a*b* values. Measurements of continuous data often varies across samples, within samples, and across measurements. The question is whether that variance is a result of common variation or deemed statistically significant. As noted earlier, the greater the sumber of decimal places reported, the more likely natural variation is observed. Mean L*a*b* values are shown in Table 4.

		Nix mini	Nix Pro 2	Spectro 1	Techkon	X-Rite 530
Red 185U	L*	59.00	55.60	58.74	57.32	58.76
	a*	57.00	60.37	61.12	62.29	62.40
	b*	32.00	27.32	29.57	27.79	29.48
Orange 021U	L*	67.00	63.98	67.49	65.90	67.19
	a*	56.00	53.36	53.80	55.90	56.05
	b*	63.00	57.37	60.26	61.77	62.90
Yellow 123U	L*	79.00	76.00	79.40	78.02	79.48
	a*	29.00	27.61	26.98	29.35	29.45
	b*	72.00	67.20	69.59	71.26	72.42
GreenU	L*	57.00	56.30	58.40	57.29	58.43
	a*	-63.00	-54.17	-54.52	-57.39	-57.41
	b*	1.00	-0.32	0.52	0.71	0.46
Blue 286U	L*	39.00	37.40	41.10	38.85	39.66
	a*	3.00	6.53	6.50	5.70	6.66
	b*	-44.00	-46.80	-43.64	-46.41	-45.62
Reflex BlueU	L*	32.00	31.70	35.40	31.63	32.53
	a*	10.00	12.50	12.60	12.31	12.96
	b*	-41.00	-42.30	-39.44	-44.06	-43.13
VioletU	L*	42.00	40.09	43.00	41.48	42.22
	a*	17.00	23.01	23.85	24.44	24.55
	b*	-34.00	-38.85	-37.18	-40.80	-39.30

**Table 4:** Mean L*a*b* values for different instruments.

When comparing mean L*a*b* readings among all pairs, all but one showed significant differences at $\alpha=0.05$, even among the two professional instruments. The mean a* values for VioletU compared between the X-Rite 530 and the Techkon SpectroDens were the only values there were statistically insignificant, with a _p_-Value above 0.05 (Figure 6). All other pair L* a* and b* differences were statistically significant at a 95% confidence level. Hypothesis H_2, _Low-cost instruments produce statistically different L*a*b* readings than professional spectrophotometers_, is confirmed. Surprisingly, we found the two professional instruments also showed statistically different mean readings for most color attributes.



Level	- Level	Difference	Std Err Dif	Lower CL	Upper CL	p-Value
Xrite	Nix Mini	7.549500	0.0134405	7.51212	7.586876	<.0001*
Techkon	Nix Mini	7.513000	0.0134405	7.47562	7.550376	<.0001*
Spectro 1	Nix Mini	6.850000	0.0134405	6.81262	6.887376	<.0001*
Nix Pro 2	Nix Mini	6.005000	0.0134405	5.96762	6.042376	<.0001*
Xrite	Nix Pro 2	1.544500	0.0134405	1.50712	1.581876	<.0001*
Techkon	Nix Pro 2	1.508000	0.0134405	1.47062	1.545376	<.0001*
Spectro 1	Nix Pro 2	0.845000	0.0134405	0.80762	0.882376	<.0001*
Xrite	Spectro 1	0.699500	0.0134405	0.66212	0.736876	<.0001*
Techkon	Spectro 1	0.663000	0.0134405	0.62562	0.700376	<.0001*
Xrite	Techkon	0.036500	0.0134405	-0.00088	0.073876	0.0590

***Figure 6:** Tukey's HSD analysis on Violet a*. Note that the mean difference between the X-Rite 530 and the Techkon SpectroDens was the only L*a*b* mean difference considered insignificant, as noted with a p-Value greater than 0.05.*

Our H_3 hypothesis stated: *Low-cost instruments have greater calculated Delta E 2000 values relative to professional spectrophotometers*. To test this, we calculated Delta E 2000 from mean readings using the formula noted in Equation 1. It should be reiterated that the reference values from the website may not match the actual printed swatch book used as the test vehicle. However, we assumed the printed formula guide should be close. We arbitrarily selected a delta target of 2.0 as a means to determine how many Delta E calculations were beyond 2.0 for the different instruments.

In addition to measuring Delta E 2000, we also looked at other aspects of color difference, including Delta a* 2000, Delta b*2000, Delta L, Delta C (chroma) and Delta H (Hue). Table 5 shows the values for the different instruments. Cells colored yellow are those above a value of 2.0.

ΔE 2000	185U	021U	123U	GreenU	286U	Reflex BlueU	VioletU
Nix mini	3.27	1.01	1.21	3.09	2.76	1.83	4.64
Nix Pro 2	3.38	3.09	3.53	3.63	0.70	2.07	3.93
Spectro 1	1.14	1.55	1.88	1.60	3.70	2.96	2.23
X-Rite	0.73	0.98	0.92	1.66	2.33	1.42	2.13
Techkon	1.78	1.25	1.77	2.64	1.90	1.52	2.53

ΔL	185U	021U	123U	GreenU	286U	Reflex BlueU	VioletU
Nix mini	0.00	0.00	1.00	3.00	2.00	1.00	2.00
Nix Pro 2	3.40	3.02	4.00	3.70	0.40	1.30	3.91
Spectro 1	0.26	0.49	0.60	0.60	4.10	2.40	1.00
X-Rite	0.24	0.19	0.52	1.57	2.66	0.47	1.78
Techkon	1.68	1.10	1.98	2.71	1.85	1.37	2.52

Δa* 2000	185U	021U	123U	GreenU	286U	Reflex BlueU	VioletU
Nix mini	8.00	3.00	2.00	4.00	5.02	4.01	10.04
Nix Pro 2	4.63	5.64	3.39	4.83	1.47	1.50	4.00
Spectro 1	3.88	5.20	4.02	4.48	1.50	1.41	3.16
X-Rite	2.60	2.95	1.55	1.59	1.34	1.04	2.46
Techkon	2.71	3.10	1.65	1.61	2.31	1.69	2.57

Δb* 2000	185U	021U	123U	GreenU	286U	Reflex BlueU	VioletU
Nix mini	2.00	1.00	4.00	2.00	4.00	7.00	9.00
Nix Pro 2	2.68	6.63	8.80	0.68	1.20	5.70	4.15
Spectro 1	0.43	3.74	6.41	1.52	4.36	8.56	5.82
X-Rite	0.52	1.10	3.58	1.46	2.38	4.87	3.70
Techkon	2.21	2.23	4.74	1.71	1.59	3.94	2.20

ΔC	185U	021U	123U	GreenU	286U	Reflex BlueU	VioletU
Nix mini	6.22	2.75	4.46	4.00	4.56	7.80	12.79
Nix Pro 2	5.33	8.70	9.43	4.84	1.41	5.89	5.63
Spectro 1	3.69	6.26	7.44	4.49	4.54	8.60	6.61
X-Rite	2.58	2.80	3.90	1.60	2.56	4.97	4.44
Techkon	3.38	3.74	5.01	1.62	1.91	4.25	3.22

ΔH	185U	021U	123U	GreenU	286U	Reflex BlueU	VioletU
Nix mini	5.41	1.55	0.35	2.00	4.51	2.05	4.28
Nix Pro 2	0.51	0.37	0.20	0.62	1.27	0.17	1.25
Spectro 1	1.27	1.34	1.36	1.50	0.80	1.16	0.46
X-Rite	0.63	1.45	0.09	1.45	0.96	0.39	0.11
Techkon	0.89	0.78	0.27	1.71	2.05	0.54	1.03

Table 5: *Delta values by instrument for the sampled colors. Reference was L*a*b* values from Pantone® Connect. Cells in yellow represent a value above 2.0.*

Figure 7 shows a line graph of the Delta E 2000 calculations from mean L*a*b* readings using the Pantone® Connect values as a reference. Since it is impossible to know what the true L*a*b* values are of the Pantone® Formula Guide and how much deviation it was to the reference values, we do not feel comfortable making a judgement as to which is "most accurate." However, it is notable that all three low-cost instruments measured one or more colors at 3.5 Delta E 2000 or above the reference, while neither of the professional devices did.

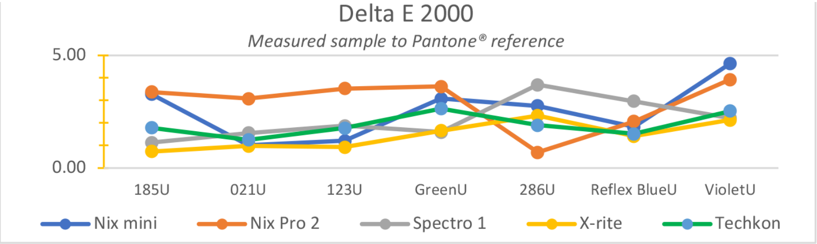


***Figure** 7: Delta E 2000 graph showing variation for all instruments.*

Two additional tables provide insight into the precision and accuracy of the instruments. When discussing targets, precision typically refers to the density or clustering of the values and accuracy refers to the proximity relative to the standard. When looking at calculations for five additional color attributes – Lightness (L), Chroma (C), Hue (H), a* and b* – Table 6 shows that the Nix Mini and the Nix Pro 2, followed by the Spectro 1 had more total readings outside of the 2.0 target, in contrast to the two professional instruments. Also, when considering the range of multiple color attributes, Table 7 provides a clear distinction between the low-cost devices and professional instruments.

Count >2.0	**185U**	**021U**	**123U**	**Green U**	**286U**	**Reflex Blue U**	**Violet U**	**Total**
Nix mini	3	2	3	4	4	4	4	24
Nix Pro 2	4	4	4	3	0	2	4	21
Spectro 1	2	3	3	2	3	3	3	19
X-Rite	2	2	2	0	3	2	3	14
Techkon	3	3	2	1	2	2	4	17
Total	14	14	14	10	12	13	18	

***Table 6:** Number of Delta value calculations above 2.0 incorporating five color attributes: Δa*00, Δb*00, ΔL, ΔC, ΔH.*

Range	**185U**	**021U**	**123U**	**Green U**	**286U**	**Reflex Blue U**	**Violet U**	**Mean Range**
Nix mini	8.00	3.00	4.11	2.00	3.02	6.80	10.79	5.39
Nix Pro 2	4.81	8.33	9.23	4.22	1.07	5.73	4.38	5.40
Spectro 1	3.62	5.77	6.84	3.89	3.74	7.44	6.15	5.35
X-Rite	2.36	2.76	3.82	0.14	1.70	4.58	4.33	2.81
Techkon	2.49	2.95	4.74	1.10	0.72	3.71	2.18	2.56

Table 7: *Range of Delta value calculations incorporating six color attributes: Δa*00, Δb*00, ΔL, ΔC, ΔH.*

When plotting the measurements grouped by instrument, we also see that the measurements are clustered tighter on the professional instruments, relative to the low-cost instruments. The Nix Mini in particular shows less precision relative to the reference values in four of the plots shown in Figure 8. The X-Rite and Techkon show tighter groupings than the others and the Techkon shows the tightest grouping in four of the six plots. From this analysis, we conclude that the professional instruments have greater precision.

This evidence points to confirm H3, that *Low-cost instruments have greater calculated Delta E 2000 values relative to professional spectrophotometers*. While we are unable to state that all Delta E 2000 readings are better from the professional instruments for multiple reasons, there is enough support based on the clustering of values and mean range for delta values of the different dimensions of color, including Delta C and Delta H, that the low-cost instruments produce higher Delta E measurement.

Interestingly, four of the instruments offered excellent values for Delta H. The Nix Pro 2 and the Spectro 1 produced excellent Delta H values, comparable to the professional devices.

Conclusions and Discussions

The purpose of this study is to determine how low-cost color measurement instruments compare to professional spectrophotometers. Two of our hypotheses were confirmed and one was rejected:

- REJECTED - H_1 – Low-cost instruments have greater measurement variation across repeated measurements than professional spectrophotometers.
- CONFIRMED - H_2 – Low-cost instruments produce statistically different L*a*b* readings than professional spectrophotometers.
- CONFIRMED - H_3 – Low-cost instruments have greater calculated Delta E 2000 values relative to professional spectrophotometers.

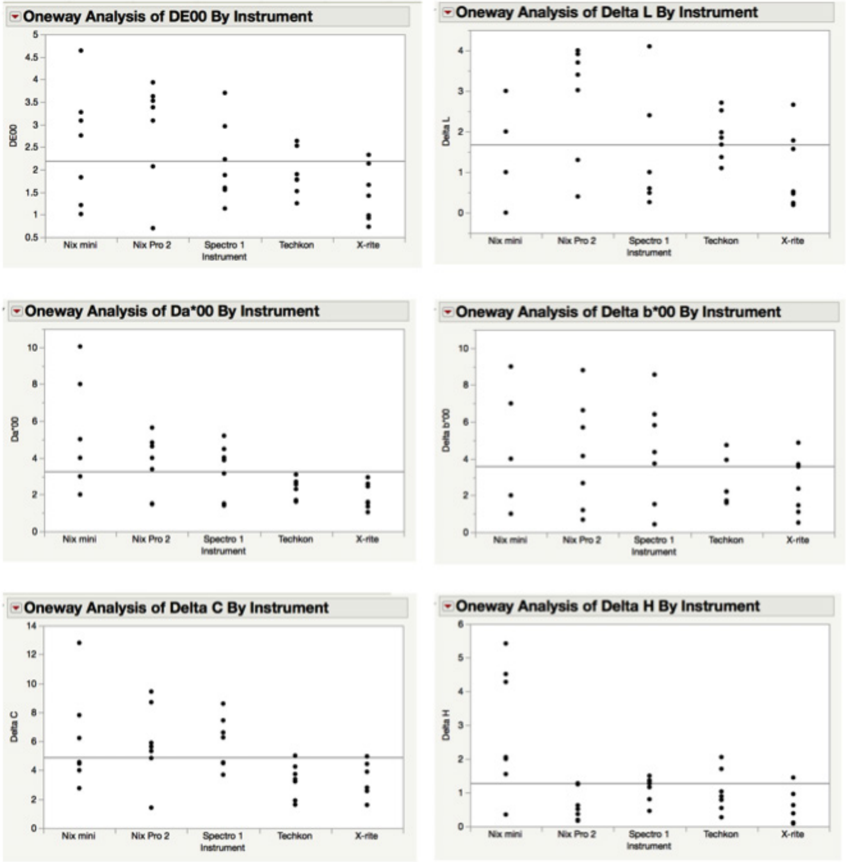


Figure 8: *Cluster plots of various color difference dimensions by instrument. Note the Y-axis changes for each plot.*

Our findings help us to draw various conclusions and notations. First, the details are important when considering the application of low-cost devices. Aperture, significant figures (decimal points), measurement conditions, accuracy, precision and feature sets all play a role in deciding if low-cost instruments are useful for one's color measurement strategy. If high precision is not important, low-cost instruments can be useful for communicating color in quantifiable terms.

Interestingly, most instruments did pretty well in measuring Hue. Referring back to Table 5, ΔH shows fairly tight values across the board. In that same table, ΔC shows the opposite, with good values only for a few measurement means.

Reflex Blue and particularly Violet presented the most challenges. Again, assuming the swatches were printed close to the digital reference values – which is not a given – several of the instruments were further away from the Delta ≤ 2.0 that we targeted.

The Nix Mini, the least expensive model, is clearly a consumer instrument and would not be great option for evaluating and communicating color in a critical way, based on the results from this study. However, for quick and less-critical measurement, it is a fine consumer device.

The strongest conclusion for this study is to focus on best practices. Based on the data we evaluated, the professional models we looked at remain the best options for critical color workflows. One significant take-away from this study is that professionals should standardize on one instrument for evaluating and communicating color. Even the professional devices show challenges with intermodel agreement. The two professional models produced statistically significant mean DE00 difference values from the same swatches, with one exception (Figure 6).

Literature Cited

Color Measurement Devices. (2015, September 21). Retrieved from x-rite: https://www.xrite.com/blog/color-measurement-devices

International Organization for Standardization. (2017). *ISO 13655:2017 Graphic technology – Spectral measurement and colorimetric computation for graphic arts images*.

Lindbloom, B. (n.d.). *Delta-E (CIE2000)*. Retrieved from brucelindbloom.com: www.brucelindbloom.com

Pantone color-finder. (n.d.). Retrieved from Pantone: https://www.pantone.com/color-finder

Precise Color Communication. (n.d.). Retrieved from Konioca Minolta: https://www.konicaminolta.com/instruments/knowledge/color/part2/06.html

Sharma, A. (2018). *Understanding Color Management* (2nd ed.). Hoboken, NJ: Wiley.

Sharma, A., Leung, E., & Adams II, R. (2017, February). Evaluation of Intermodel Agreement Using ISO 13655 M0, M1, and M2 Measurement Modes in Commercial Spectrophotometers. *Color Research and Application*, pp. 27-37.

Understanding Illuminants. (n.d.). Retrieved from x-rite: https://www.xrite.com/service-support/understanding_illuminants

Understanding Standard Observers in Color Management. (n.d.). Retrieved from Konica Minolta: https://sensing.konicaminolta.us/us/blog/understanding-standard-observers-in-color-measurement/

X-Rite Color. (2015, September 21). *X-Rite Color Blog | Color Measurement Devices*. Retrieved from X-Rite Color: https://www.xrite.com/blog/color-measurement-devices