

Sigma Merrill vs. Sigma Quattro. 3. Color

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Summary

A Sigma DP2 Merrill and dp2 Quattro were used to photograph a 24-patch ColorChecker Classsic. Image processing (X3F and TIFF) was limited to global adjustments to white balance and exposure. Color reproduction of each of the 18 non-gray-scale patches was evaluated by comparison to the published ColorChecker (2005) L*a*b* coordinates. For both cameras, portrait color mode produced the best match to the ColorChecker. Overall, the Merrill images were a closer match to the reference values, although the difference between cameras was generally not large.

Key words: Sigma Quattro, Sigma Merrill, DP2, dp2, ColorChecker, Sigma Photo Pro, BabelColor, LCh color model

1. Introduction

The Sigma Merrill cameras, and the more recently introduced Quattros, are unique among current cameras in using a Foveon sensor. Although they occupy a small niche, the Merrills have enthusiastic supporters. That enthusiasm is based mostly on exceptional image acuity that can be attributed to the Foveon sensor design and excellent optics. That exceptional acuity comes, however, in a modest package that entails some serious compromises. The Merrills are essentially point-and-shoot cameras with fixed, prime lenses that have relatively slow (f/2.8) maximum apertures. They have APS-C size sensors with "only" 14.75 MP, and no built-in or add-on electronic viewfinder. In addition to these rather modest specifications, the Merrills have very short battery life, perform poorly above ISO 400, and are frequently described as having idiosyncratic color reproduction. The Quattro series of cameras is Sigma's next iteration of the Foveon concept. Despite a significant upgrade to the rear LCD and an unconventional overall shape, they retain the essential point-and-shoot nature of the Merrills: fixed prime lenses and no EVF. What the Quattros do have, however, is a significantly re-designed 19.6 MP sensor (still APS-C format).

In the previous two papers in this series, I described the design differences between the Merrill and Quattro sensors, investigated their signal-to-noise ratios and ISO performance, and compared image acuity.[1] In this paper, I examine color reproduction: are there appreciable differences between Merrill and Quattro cameras; is one "better" than the other; if so, how?

[1] Service, Phil. 2016. Sigma Merrill vs. Sigma Quattro. 1. Signal, Noise, and Sensor Design.
Service, Phil. 2016. Sigma Merrill vs. Sigma Quattro. 2. Image Comparison.

These results apply only to images made at base ISO (ISO 100). The relative performances of the two cameras might be substantially different at higher ISO.

2. Methods

A DP2 Merrill and dp2 Quattro were used to photograph an X-Rite ColorChecker Classic[2] in direct mid-day sun. The camera-subject distance was such that the ColorChecker filled about 80% of the frame (by area). Exposures were made with the camera color mode set to *Standard, Neutral, Portrait and Landscape.* All images were shot at ISO 100 and f/5.6, and bracketed ± 0.3 EV, using the camera's evaluative (matrix) metering. Raw (X3F) files were processed with Sigma Photo Pro 6.3.2, according to the in-camera color mode. The *only* adjustments were to white balance and exposure. I used the neutral 5 gray patch of the ColorChecker to set white balance (fourth patch from left on bottom row). I adjusted exposure so that the RGB values of that same gray patch were approximately 120-121, which are its reference-standard Adobe RGB values. For each bracketed triplet, I chose for analysis the image that most closely matched the neutral 5 target value *before* exposure adjustment. Selected images were examined with RawDigger to ensure that no color patches were over- or underexposed in any color channel.

Images were exported from Photo Pro as 16-bit TIFFs, and opened in Adobe Camera Raw. White balance was repeated in ACR, again using the neutral 5 patch. In two cases, an additional very small exposure correction was also made in ACR. Lastly images were opened in Photoshop CC 2015. The color sampler tool was used to obtain the L*a*b* coordinates from a 101 x 101 pixel sample in the center of each of the 18 colored (non-gray-scale) patches of the ColorChecker image.[3] The Adobe RGB (1998) color space was used throughout the workflow. *It is important to understand that no color adjustments were made to the images beyond those resulting from global white balance and exposure corrections.*

I compared the measured Lab color coordinates to reference values provided by BabelColor.[4] Lab coordinates, and their simple transformation to LCh_{ab} were used because they lend themselves to relatively intuitive and easy-to-calculate metrics of color difference (ΔE). Specifically, I calculated ΔE (CIE 1976), ΔE (CIE 1994) and ΔE (CMC 1:1).[5] In Lab, colors are represented as points in 3-dimensional space defined by the axes of the three coordinates: L*, a* and b*. ΔE (CIE 1976) is simply the geometric distance between two points in Lab space. Since 1976, several additional metrics have been introduced in order to achieve better correspondence

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[2] A pre-November 2014 example. For information about changes to the ColorChecker Classic in November 2014, see here. The ColorChecker is sometimes called the Macbeth ColorChecker or the Gretag-Macbeth ColorChecker. A brief history can be found at BabelColor.

[3] It is common practice to refer to the CIE L*a*b* color model as Lab color (without asterisks). I will generally follow that practice, but include asterisks when referring to individual color coordinates (*e.g.*, a*).

[4] Pascale, Danny. 2000-2006. RGB coordinates of the Macbeth ColorChecker. Specifically, I used the coordinates referred to as "ColorChecker 2005".

[5] Formulas for calculating these metrics can be found at http://www.brucelindbloom.com. Follow the link to "Math".

between calculated and perceived color differences. ΔE (CIE 1994) and ΔE (CMC 1:1) are two such metrics. Both are based on transformation of Lab coordinates to L*C*h coordinates. L* (lightness) is the same in both models. C* refers to chroma. It is the distance on the a*-b* plane from the central, neutral L* axis of the Lab space. Chroma depends only on the *absolute* values of a* and b*. "h" is hue, expressed as an angle (in degrees) about the central axis.[6] It depends on the *relative* values of a* and b*, and on their signs (+ or -). LCh is analogous to HSB (hue, saturation, brightness), which is a transformation of RGB coordinates. ColorChecker L*C*h reference coordinates are given in Table A1 in the Appendix.

3. Results

3.1. Summary Statistics by Camera and Color Mode

Results for the DP2 Merrill and dp2 Quattro are summarized in Tables 1M and 1Q, respectively. Exposure adjustment based on the neutral 5 patch worked well, overall: average ΔL* was generally between ±1.0. For both cameras, *Portrait* mode produced the best match to the ColorChecker reference coordinates, by all three measures of ΔE. Fig. 1 shows *Portrait* mode images for both cameras, together with a simulated ColorChecker image made with reference color coordinates.[7] *Landscape* mode gave the poorest overall match. *Standard* mode (which is the camera default) generally produced the second closest match to the reference values. Considering all four color modes, the Merrill images were a closer match to reference values. That does not necessarily mean, however, that the Merrill reproduced the ColorChecker more "accurately", as I will explain in the Discussion. Furthermore, given that the intent of modes such as *Landscape* is to "enhance" colors, it is pointless, in many cases, to say that one camera did a better job than the other of matching reference color coordinates. Images processed with the four color modes can be seen in Fig. 2 (Merrill) and Fig. 3 (Quattro).

For both cameras, differences between color modes appear to be based mostly on altering saturation. For example, *Neutral* mode reduces chroma on average (negative ΔC* in Tables 1M and 1Q); and *Landscape* mode strongly increases chroma (positive ΔC*). Over all four color modes, the Merrill did render hues more closely to reference values. That probably accounts for most of the difference in ΔE values between cameras.

3.2. Analysis by Color Patch and Camera

Results for ΔE (CIE 1994) are given in Tables 2M and 2Q; and results for ΔE (CMC 1:1) are in Tables 3M and 3Q. Although *Landscape* mode gives the poorest overall match to the

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[6] Formulas for calculating LCh_{ab} coordinates from Lab coordinates can be found at the reference in Footnote 5. Notation on the web is inconsistent. The proper designation of the individual color components is L*, C*, h. "h" is lower case and does not have an asterisk. Hue *difference* is properly designated as ΔH*. It is important to note that this is NOT the hue *angle difference*, which is Δh. ΔH* is used in formulas for ΔE because it is in the same "units" as L*, a*, and b*. See CIE Technical Report, Colorimetry, 3rd ed., CIE 15:2004.

[7] All figures are in separate files that may be accessed by clicking on the links in the text: *e.g.*, Fig. 1. Simulated ColorChecker reference image obtained from BabelColor.

Table 1M. DP2 Merrill Color Difference Summary

Color Mode	Photo Pro Exp. Adj.††	Average† ΔL*	Average† ΔC*‡	Average† ΔH*‡	Average† ΔE (CIE 1976)	Average† ΔE (CIE 1994)	Average† ΔE (CMC 1:1)
Standard	+0.1	-0.434	1.747	3.173	7.545	5.103	5.155
Neutral	+0.1	0.360	-4.204	3.799	8.487	5.197	5.726
Portrait	+0.3	-0.380	0.771	3.582	7.307	4.951	5.095
Landscape	+0.2	-0.036	9.022	4.004	11.925	6.355	6.906

† Average values over 18 color (non-gray-scale) patches. Difference statistics based on comparison of images to reference ColorChecker (2005) values. (See text for details).
†† All images taken at f/5.6, 1/1250 sec, with -0.3 EV exposure compensation in-camera.
‡ C* is chroma and h is hue in the LCh color model. These color components are similar to saturation and hue in the HSB color model. LCh is a simple transformation of Lab. ΔH* converted to absolute values so that negative and positive differences do not cancel each other out. Although h is expressed as an angle (in degrees), ΔH* is expressed in the same "units" as the a* and b* components of Lab color.

Table 1Q. dp2 Quattro Color Difference Summary

Color Mode	Photo Pro Exp. Adj.††	Average† ΔL*	Average† ΔC*‡	Average† ΔH*‡	Average† ΔE (CIE 1976)	Average† ΔE (CIE 1994)	Average† ΔE (CMC 1:1)
Standard	-0.7	-1.359	3.004	5.710	9.892	6.347	6.784
Neutral	-0.5	-0.982	-4.702	5.808	10.094	6.120	6.815
Portrait	-0.7	-0.612	-1.757	5.319	8.156	5.449	5.778
Landscape	-0.5	-1.032	9.900	5.736	13.907	7.464	8.330

† Average values over 18 color (non-gray-scale) patches. Difference statistics based on comparison of images to reference ColorChecker (2005) values. (See text for details).
†† All images taken at f/5.6, 1/1000 sec, with -0.3 EV exposure compensation in-camera.
‡ C* is chroma and h is hue in the LCh color model. These color components are similar to saturation and hue in the HSB color model. LCh is a simple transformation of Lab. ΔH* converted to absolute values so that negative and positive differences do not cancel each other out. Although h is expressed as an angle (in degrees), ΔH* is expressed in the same "units" as the a* and b* components of Lab color.

Table 2M. DP2 Merrill: Color Mode and ΔE (CIE 1994) for X-Rite Color Checker (2005)

		Color Mode*				Average
		Standard	Neutral	Portrait	Land-scape	
1	dark skin	11.48	7.06	8.09	11.65	9.57
2	light skin	2.48	4.38	2.54	5.02	3.60
3	blue sky	4.23	5.24	4.07	5.28	4.71
4	foliage	10.17	6.04	7.07	9.44	8.18
5	blue flower	7.07	6.17	5.45	5.83	6.13
6	bluish green	5.49	4.69	2.85	4.37	4.35
7	orange	9.19	7.49	7.40	6.86	7.73
8	purplish blue	9.33	6.97	6.59	5.62	7.13
9	moderate red	3.19	3.98	0.98	5.18	3.33
10	purple	10.78	3.72	4.74	8.25	6.87
11	yellow green	10.48	3.13	4.82	4.82	5.81
12	orange yellow	6.70	6.01	6.27	5.55	6.13
13	blue	3.86	3.82	4.17	4.47	4.08
14	green	9.78	4.79	5.65	7.75	6.99
15	red	12.39	3.52	3.94	9.16	7.25
16	yellow	3.32	3.93	4.29	1.66	3.30
17	magenta	4.26	4.84	2.34	5.02	4.12
18	cyan	11.62	7.76	7.86	8.46	8.93
Average		7.55	5.20	4.95	6.36	

* Least ΔE for each ColorChecker color is highlighted

Table 2Q. dp2 Quattro: Color Mode and ΔE (CIE 1994) for X-Rite Color Checker (2005)

		Color Mode*				Average
		Standard	Neutral	Portrait	Land-scape	
1	dark skin	11.94	9.29	5.00	13.70	9.98
2	light skin	6.41	6.57	4.82	11.12	7.23
3	blue sky	5.63	4.93	4.19	5.68	5.11
4	foliage	9.91	7.90	6.52	10.53	8.71
5	blue flower	6.63	6.96	5.21	5.82	6.15
6	bluish green	1.99	4.79	2.54	2.36	2.92
7	orange	7.92	8.31	7.77	7.82	7.96
8	purplish blue	7.36	7.44	7.98	3.42	6.55
9	moderate red	5.19	5.76	3.09	8.68	5.68
10	purple	6.11	2.65	2.19	9.18	5.03
11	yellow green	7.07	5.98	6.82	7.56	6.86
12	orange yellow	6.95	7.62	8.46	5.63	7.17
13	blue	1.68	2.71	7.27	6.30	4.49
14	green	5.45	4.96	4.43	7.75	5.65
15	red	8.57	7.29	6.40	10.64	8.23
16	yellow	4.38	5.65	6.04	2.59	4.66
17	magenta	1.87	4.04	1.73	5.83	3.37
18	cyan	9.20	7.31	7.60	9.72	8.46
Average		6.35	6.12	5.45	7.46	

* Least ΔE for each ColorChecker color is highlighted

Table 3M. DP2 Merrill: Color Mode and ΔE (CMC(1:1)) for X-Rite Color Checker (2005)

		Color Mode*				Average
		Standard	**Neutral**	**Portrait**	**Land-scape**	
1	dark skin	10.53	8.07	8.99	12.99	10.15
2	light skin	2.89	6.53	4.11	7.68	5.30
3	blue sky	3.78	5.13	3.79	5.16	4.47
4	foliage	8.41	6.10	7.24	9.94	7.92
5	blue flower	5.20	5.89	5.09	5.21	5.35
6	bluish green	3.22	5.23	2.83	3.56	3.71
7	orange	6.59	11.09	7.97	6.13	7.94
8	purplish blue	7.30	7.50	7.09	6.00	6.97
9	moderate red	1.38	4.62	1.10	6.25	3.34
10	purple	6.18	4.07	5.33	9.54	6.28
11	yellow green	4.80	2.96	4.95	5.81	4.63
12	orange yellow	4.78	5.73	4.92	4.70	5.03
13	blue	3.88	4.89	5.26	5.63	4.92
14	green	5.20	4.28	5.21	8.52	5.80
15	red	5.69	4.42	4.94	11.81	6.71
16	yellow	2.37	3.83	3.22	1.39	2.70
17	magenta	2.48	4.85	2.12	6.20	3.91
18	cyan	8.11	7.88	7.51	7.79	7.82
Average		5.16	5.73	5.09	6.91	

* Least ΔE for each ColorChecker color is highlighted

Table 3Q. dp2 Quattro: Color Mode and ΔE (CMC(1:1)) for X-Rite Color Checker (2005)

		Color Mode*				Average
		Standard	Neutral	Portrait	Land-scape	
1	dark skin	12.99	10.28	5.87	15.05	11.05
2	light skin	10.87	10.74	8.21	17.82	11.91
3	blue sky	5.94	4.88	4.24	5.86	5.23
4	foliage	10.06	7.98	6.66	10.85	8.89
5	blue flower	6.59	7.12	5.50	5.17	6.10
6	bluish green	2.21	5.65	2.73	2.10	3.17
7	orange	7.16	11.18	7.92	6.84	8.28
8	purplish blue	8.59	8.57	9.17	4.10	7.61
9	moderate red	5.80	6.71	3.55	10.06	6.53
10	purple	7.29	3.21	2.58	10.91	6.00
11	yellow green	7.09	5.95	6.48	8.09	6.90
12	orange yellow	5.40	6.80	6.52	4.42	5.79
13	blue	2.07	3.35	8.99	7.93	5.58
14	green	5.32	4.56	4.05	8.74	5.67
15	red	10.85	9.10	8.10	13.65	10.43
16	yellow	3.25	4.80	4.48	2.37	3.73
17	magenta	2.01	4.57	1.72	7.00	3.82
18	cyan	8.61	7.20	7.22	8.98	8.01
Average		6.78	6.81	5.78	8.33	

* Least ΔE for each ColorChecker color is highlighted

Table 4M. DP2 Merrill: Color Mode and ΔL* for X-Rite Color Checker (2005)

		Color Mode†				Average
		Standard	Neutral	Portrait	Land-scape	
1	dark skin	-8.90	-6.69	-7.23	-9.43	-8.06
2	light skin	0.82	1.40	0.46	1.65	1.08
3	blue sky	4.02	4.61	3.98	4.66	4.32
4	foliage	-6.17	-4.42	-4.67	-6.21	-5.37
5	blue flower	5.19	5.33	4.93	5.67	5.28
6	bluish green	2.47	1.73	1.54	4.00	2.44
7	orange	-6.96	-4.83	-6.64	-6.51	-6.24
8	purplish blue	5.91	6.41	5.97	5.26	5.89
9	moderate red	-0.49	1.81	-0.26	-1.21	-0.04
10	purple	-1.59	0.13	-0.45	-1.92	-0.96
11	yellow green	-1.10	-1.47	-1.86	1.00	-0.86
12	orange yellow	-6.05	-5.29	-6.22	-5.30	-5.72
13	blue	2.80	3.52	3.59	1.84	2.94
14	green	-3.16	-2.79	-3.20	-1.83	-2.75
15	red	-1.15	-0.40	-1.42	-0.31	-0.82
16	yellow	-3.23	-3.16	-4.24	-1.51	-3.04
17	magenta	2.29	4.22	2.31	1.24	2.51
18	cyan	7.49	6.38	6.58	8.26	7.18
Average		-0.43	0.36	-0.38	-0.04	

† Least ΔL* (absolute value) for each ColorChecker color is highlighted

Table 4Q. dp2 Quattro: Color Mode and ΔL* for X-Rite Color Checker (2005)

		Color Mode†				Average
		Standard	**Neutral**	**Portrait**	**Land-scape**	
1	dark skin	-10.93	-9.05	-4.63	-11.88	-9.12
2	light skin	1.09	0.91	-0.46	2.89	1.11
3	blue sky	4.06	4.28	3.45	4.27	4.02
4	foliage	-7.25	-5.80	-2.98	-7.83	-5.96
5	blue flower	5.38	5.13	3.59	5.72	4.95
6	bluish green	0.75	-0.05	-1.22	2.05	0.38
7	orange	-7.63	-6.25	-7.18	-7.53	-7.15
8	purplish blue	4.03	4.75	5.16	1.64	3.90
9	moderate red	-2.13	0.01	-0.16	-2.90	-1.30
10	purple	-3.95	-2.25	1.65	-5.06	-2.40
11	yellow green	-1.05	-2.17	-2.69	1.81	-1.03
12	orange yellow	-6.92	-7.04	-8.46	-5.58	-7.00
13	blue	0.64	1.58	4.74	-1.45	1.38
14	green	-1.63	-2.57	-2.12	0.42	-1.48
15	red	-1.88	-1.60	-0.13	-0.83	-1.11
16	yellow	-4.33	-5.22	-6.00	-2.14	-4.43
17	magenta	0.53	2.59	1.52	-0.84	0.95
18	cyan	6.76	5.08	4.91	8.66	6.35
Average		-1.36	-0.98	-0.61	-1.03	

† Least ΔL* (absolute value) for each ColorChecker color is highlighted

Table 5M. DP2 Merrill: Color Mode and ΔC* for X-Rite Color Checker (2005)

		Color Mode†				Average
		Standard	Neutral	Portrait	Land-scape	
1	dark skin	7.25	2.67	6.44	12.60	7.24
2	light skin	-0.63	-5.17	-2.08	5.08	-0.70
3	blue sky	-1.32	-4.29	-1.60	3.93	-0.82
4	foliage	3.43	1.02	4.36	10.81	4.90
5	blue flower	-4.77	-6.79	-4.97	2.24	-3.57
6	bluish green	-3.97	-10.35	-4.32	1.92	-4.18
7	orange	5.14	-3.22	3.56	8.76	3.56
8	purplish blue	-5.63	-8.51	-5.52	5.87	-3.45
9	moderate red	3.02	-8.88	-0.53	12.86	1.62
10	purple	9.30	4.88	8.48	17.41	10.02
11	yellow green	6.59	-1.58	7.69	14.15	6.71
12	orange yellow	2.77	-1.66	1.58	4.04	1.68
13	blue	-1.75	-4.97	-3.55	11.58	0.33
14	green	5.45	-1.63	4.88	17.85	6.64
15	red	10.73	-1.00	8.11	21.77	9.90
16	yellow	-0.70	-6.06	-1.82	0.27	-2.08
17	magenta	3.59	-7.84	0.67	15.60	3.00
18	cyan	-7.04	-12.28	-7.51	-4.35	-7.80
Average		1.75	-4.20	0.77	9.02	

† Least ΔC* (absolute value) for each ColorChecker color is highlighted

Table 5Q. dp2 Quattro: Color Mode and ΔC* for X-Rite Color Checker (2005)

		Color Mode†				Average
		Standard	Neutral	Portrait	Land-scape	
1	dark skin	8.97	2.64	2.16	12.70	6.62
2	light skin	0.32	-5.27	-1.20	8.84	0.67
3	blue sky	1.47	-2.56	-0.78	6.50	1.16
4	foliage	3.91	-1.08	-1.62	8.67	2.47
5	blue flower	-6.85	-9.42	-6.58	-1.16	-6.01
6	bluish green	-4.37	-11.96	-5.19	2.87	-4.66
7	orange	5.51	-2.10	3.79	8.47	3.92
8	purplish blue	-3.58	-9.12	-7.94	7.84	-3.20
9	moderate red	5.06	-7.66	-2.16	15.53	2.69
10	purple	10.74	3.01	1.87	18.02	8.41
11	yellow green	6.59	-6.82	0.19	14.05	3.50
12	orange yellow	1.91	-2.98	0.63	2.89	0.61
13	blue	3.20	-3.80	-7.30	17.64	2.43
14	green	7.64	-4.02	-3.01	19.17	4.94
15	red	15.12	2.62	6.35	23.06	11.79
16	yellow	-1.06	-7.11	-2.89	0.13	-2.73
17	magenta	3.85	-10.17	-2.70	16.89	1.97
18	cyan	-4.35	-8.83	-5.26	-3.89	-5.59
Average		3.00	-4.70	-1.76	9.90	

† Least ΔC* (absolute value) for each ColorChecker color is highlighted

Table 6M. DP2 Merrill: Color Mode and ΔH* (absolute value) for X-Rite Color Checker (2005)

		Color Mode†				Average
		Standard	Neutral	Portrait	Land-scape	
1	dark skin	0.06	2.30	1.58	1.79	1.43
2	light skin	2.25	4.67	3.17	5.68	3.94
3	blue sky	0.00	1.71	0.40	2.01	1.03
4	foliage	7.32	5.65	6.78	6.96	6.68
5	blue flower	0.58	0.62	0.83	1.27	0.83
6	bluish green	2.88	2.09	2.50	2.37	2.46
7	orange	3.08	11.41	6.31	0.22	5.25
8	purplish blue	4.53	0.53	3.67	0.97	2.43
9	moderate red	0.91	4.05	1.63	5.60	3.05
10	purple	5.21	4.59	4.65	5.23	4.92
11	yellow green	8.07	5.27	7.63	5.56	6.63
12	orange yellow	0.77	5.83	1.47	2.76	2.71
13	blue	2.00	0.28	3.27	3.85	2.35
14	green	7.49	6.72	7.69	8.92	7.70
15	red	6.08	6.63	5.64	13.40	7.94
16	yellow	0.23	4.24	1.17	1.51	1.79
17	magenta	0.23	0.53	0.66	2.44	0.97
18	cyan	5.40	1.27	5.43	1.54	3.41
Average		3.17	3.80	3.58	4.00	

† Least ΔH* for each ColorChecker color is highlighted

Table 6Q. dp2 Quattro: Color Mode and ΔH* (absolute value) for X-Rite Color Checker (2005)

		Color Mode†				Average
		Standard	Neutral	Portrait	Land-scape	
1	dark skin	0.72	2.07	1.97	1.30	1.52
2	light skin	8.73	8.32	6.59	13.70	9.33
3	blue sky	5.11	2.79	3.13	2.53	3.39
4	foliage	9.01	7.38	7.95	7.98	8.08
5	blue flower	3.25	2.79	3.27	1.31	2.65
6	bluish green	0.87	0.48	1.22	0.38	0.74
7	orange	3.25	10.98	5.69	0.54	5.12
8	purplish blue	10.34	8.40	9.45	2.82	7.75
9	moderate red	7.88	9.30	5.32	11.79	8.57
10	purple	2.12	0.98	1.80	2.62	1.88
11	yellow green	13.06	10.18	12.09	12.24	11.89
12	orange yellow	0.86	5.83	0.38	0.48	1.89
13	blue	2.17	3.36	9.04	5.62	5.05
14	green	8.08	7.06	6.59	8.66	7.60
15	red	13.93	13.48	11.76	16.38	13.89
16	yellow	1.24	3.31	0.30	3.19	2.01
17	magenta	2.45	1.05	0.39	4.95	2.21
18	cyan	9.72	6.79	8.82	6.75	8.02
Average		5.71	5.81	5.32	5.74	

† Least ΔH* for each ColorChecker color is highlighted

ColorChecker reference coordinates for both cameras, it does give the best match for some colors: particularly orange (7), purplish blue (8), orange yellow (12) and yellow (16).[8] Patches 7, 12, and 16 are the three with the highest reference chroma (C*). Given that Landscape mode increases saturation, it is perhaps logical that it does well with those three colors. On the other hand, the reference chroma for purplish blue (8) is close to average. Interestingly, *Standard mode* (default setting) produced the fewest number of "best" color matches.

For both cameras, dark skin (1) was the most problematic patch: there was a strong tendency to underestimate lightness (Tables 4M and 4Q), and overestimate chroma (Tables 5M and 5Q); while hue was quite accurately rendered (Tables 6M and 6Q). Dark skin has the lowest chroma and third lowest lightness of all non-gray-scale patches (Table A1). Other colors that both cameras generally had difficulty matching were foliage (4), orange (7), purplish blue (8), and red (15). I do not see any pattern for these four colors. For both cameras, foliage (4) was difficult to match in terms of lightness and hue: too dark and too yellow. The miss on red (15) was chiefly on chroma and hue: too saturated and too orange, although much of the over saturation was due to *Landscape* mode. Orange (7) was consistently too dark, and hue was moved in the direction of more yellow. For both cameras, purplish blue (8) was too light, and had too little chroma, except in *Landscape* mode. The Quattro also tended to shift the hue of purplish blue towards cyan.

Purple (10) and cyan (18) were problematic for the Merrill only. Purple was too saturated (Table 5M), and hue was consistently moved toward magenta. The lightness of cyan was overestimated, and chroma underestimated (Tables 4M and 5M). Light skin (2) was problematic only for the Quattro: the hue was too orange.

4. Discussion

An obvious question is: how does color reproduction by these Sigma cameras compare to other cameras? The short answer is: I don't know. I've not performed similar analyses with any other camera, nor have I seen comparable analyses elsewhere. It is quite possible that there simply is not much interest in these kinds of tests, beyond using them for camera profiling. Color preference is essentially subjective: most photographers probably aren't that much interested in color "accuracy".

Does the Merrill do a "better" job than the Quattro of reproducing color? For several reasons, I think there is no clear-cut answer to that question. First, we do not know if Sigma's engineers were even trying for exact color reproduction. The fact that *Portrait* mode provides the closest match to ColorChecker, rather than, say, *Standard* or *Neutral*, suggests that absolute fidelity is less of a consideration than overall "look", or effect. The existence of color modes such as *Vivid* and *Foveon Blue* emphasizes that subjective qualities may often be more important than fidelity. In fact, I do not know if absolute fidelity of color reproduction is even possible with current sensor technology — Foveon or otherwise.

A second reason to be cautious about claims that one camera is "better" than the other has to do with the procedures used in these tests: specifically the fact that only one ColorChecker

[8] The "best" matches for each color, across color modes, are highlighted in Tables 2M, 2Q, 3M, 3Q, 4M, 4Q, 5M, 5Q, 6M, and 6Q.

was photographed. The spectral reflectances of that particular example of the ColorChecker are unknown. Images were compared to *published* color coordinates. We do not know how well my ColorChecker matched those coordinates. Thus, it is at least possible that the Quattro did a better job than the Merrill of matching the colors of the chart that was actually used. We know from studies published by BabelColor that there are measurable differences between individual ColorChecker charts;[9] and the manufacturer (X-Rite) cautions that colors may change over time and with use, and recommends that charts be replaced every two years.[10] Lastly, the current tests were made at ISO 100: there is substantial reason to believe that Merrill color reproduction will deteriorate more quickly as ISO is increased.[11]

[9] Pascale, Danny. 2000-2006. RGB coordinates of the Macbeth ColorChecker.

[10] http://xritephoto.com/ph_product_overview.aspx?ID=938&Action=Support&SupportID=5879&catid=28

[11] Service, Phil. 2016 Sigma Merrill vs. Sigma Quattro. 1. Signal, Noise, and Sensor Design

Appendix

Table A1. ColorChecker (2005) LCH Coordinates

		L*	C*	h
1	dark skin	37.99	19.53	46.05
2	light skin	65.71	25.41	44.49
3	blue sky	49.93	22.46	257.45
4	foliage	43.14	25.52	120.87
5	blue flower	55.11	26.89	289.20
6	bluish green	70.72	33.40	180.34
7	orange	62.66	67.53	57.72
8	purplish blue	40.02	47.13	282.76
9	moderate red	51.12	50.90	18.61
10	purple	30.33	31.53	316.79
11	yellow green	72.53	61.97	112.49
12	orange yellow	71.94	70.57	74.07
13	blue	28.78	52.26	285.74
14	green	55.26	49.54	140.71
15	red	42.10	60.36	27.84
16	yellow	81.73	79.92	87.10
17	magenta	51.94	52.07	343.75
18	cyan	51.04	40.50	225.01