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RESEARCH ARTICLE

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Bidirectional individual corresponding colors data

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Abstract

The precision of corresponding colors data is critical to improve chromatic adaptation models. This research aims to obtain high precision and individually resolved corresponding colors data, as well as to look into the reversibility of chromatic adaptation. The experiment included 2 phases. The illumination changes were simply reverses of one another. The mean results of the forward phase across 9 observers were adopted as the test colors in the reverse phase. The CIEDE2000-unit standard deviations of the results across 9 observers in the forward and reverse phases are 2.81 and 2.56, respectively. The standard error of the mean of the results of individual observers and across 9 observers of the 2 phases are all less than 1.0 CIEDE2000 unit, very significantly more precise than previously reported data. Nevertheless, by examination of the bidirectional procedures, it is concluded that there might be need to improve accuracy or contemplate a reality in which chromatic adaptation is not a reversible process (ie, has a significant hysteresis effect). The mean biases between the test colors of the forward phase and the visual results of the reverse phase for each individual across 5 colors are averaged at 7.2 CIEDE2000 units. The average value for overall data is nearly 6.0 CIEDE2000 units. This indicates that chromatic adaptation in this experiment is not reversible. The discrepancies are rather large and need to be explored further. One possible, but by no means definitive, explanation is that the biases are might be caused by memory distortions in the experiment.

KEYWORDS

accuracy, bidirectional adaptation, corresponding colors data, individual differences, precision

1 | INTRODUCTION

Corresponding colors data are critical for the research and formulation of chromatic adaptation models and transforms.[1–6] They are collected by psychophysical experiments. Many experiments have been carried out using a variety of psychophysical methods under different viewing conditions across several decades.[7–13] Nevertheless they were mostly undertaken by a panel of a small number of observers with typically a single observation per observer. Kuo et al. (1995) found that typical inter-observer variation for studying chromatic adaptation was about 4 CMC (1:1) units (which are similar in magnitude to CIEDE2000 color difference units and approximately half the size of CIELAB color difference units).[2] Hence, if a chromatic adaptation transform has an error of prediction for a single observation equal to, or less than, 4 units (6–8 units in CIELAB), it might be considered satisfactory. Only when the precision of the data is improved can the chromatic adaptation models and transforms be improved. Thus, the accuracy of individual corresponding colors data has never been fully explored because the high-precision results of observers, or even populations have not been known.

To collect highly precise corresponding colors data, an experimental protocol has been designed and implemented by the authors early on.[14] The research in this article is an advancement based on that. The experiments undertaken are, respectively, denoted as experiment I and experiment II in this article. Their experimental steps are almost the same except that experiment II included 2 phases to explore the

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TABLE 1 Absolute (cd/m^2 from a diffuse white reference) and relative tristimulus values of the incandescent (A) and daylight (D65) illumination used in the experiments

	Incandescent (A)			Daylight (D65)		
	Xrw	Yrw	Zrw	Xw	Yw	Zw
Mean measurement	473.40	437.60	160.50	325.00	341.20	397.10
Normalized results	108.18	100.00	36.67	95.25	100.00	116.38

reversibility of chromatic adaptation. A brief but necessary description is given below for experiment I.

The experiments employed short-term memory matching to obtain corresponding colors data. In experiment I, 5 test colors were evaluated by 6 observers (all with normal color vision) with 30 repeat trials across 1 change in illumination (from incandescent illumination to simulated daylight). The test colors were red, blue, green, yellow and a tan color. Their L^* values range approximately from 40 to 86. The side dimension of each square color patch was 2.2 cm calculated in terms of the viewing distance of about 65 cm to produce a 2° viewing field. Two test color patches were put on each test sheet with 4.5 cm distance between them to avoid direct simultaneous contrast influence on each other.[15] There were 5 test sheets and each color appears twice. Each of ten test color patch had its corresponding reference sheet which has 4 × 4 square color patches (2.2 cm for each side and distance) with enough color range for observers to choose a satisfactory corresponding color. All the test color patches and reference color patches were printed on a Canon iPF6400 printer using Onyx Rip-Queue 11 printing software with Gold Fibre Silk paper (310 g/m^2) and Canon Lucian ink.

The 2 adaptation light sources adopted for the experiment were illuminant A and illuminant D65 simulators. They were provided by incandescent and daylight of GTI Colormatcher CMB-3064 light booth which is 76 cm height, 163 cm width, and 76 cm depth. Their mean tristimulus values measured with PhotoResearch PR-655 from a white reference standard are shown in Table 1. It should be noted that the luminance of the 2 adapting light sources is not identical (437.60 cd/m^2 and 341.20 cd/m^2). However, this is not a significant luminance difference in terms of the experimental protocol and it is not expected that luminance differences significantly impact corresponding colors results until they are roughly an order of magnitude.[4] Observers in the experiments did not notice brightness differences between the 2 illumination conditions.

Figure 1 shows the experimental scene. A sample holder was put at the center of the light booth and the illuminating/viewing geometry is 45°/0°. A test sheets collection and a reference sheets collection were put, respectively, on the 2 sides of the sample holder. An audio recording was made in advance to remind the observers of each step as they proceeded. Observers put the corresponding collection on the sample holder successively with the proper sheet uppermost according to the audio instruction. The 2 light sources were switched automatically by pre-programming. Each observer commenced an observing session by adapting to the incandescent illumination for a period of 2 minutes.[16,17] Then they

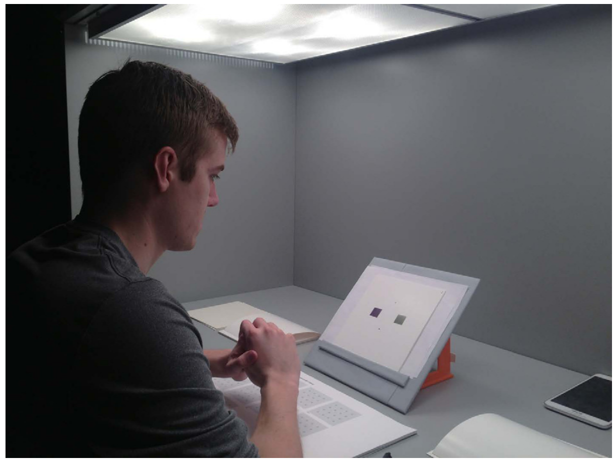

FIGURE 1 Experimental scene. An observer sat in front of the light booth with an answer sheet before him. A sample holder was put in the center of the light booth. A test sheet collection and a reference sheet collection were put, respectively, on the 2 sides of the sample holder. They were put on the sample holder successively by the observer according to automated audio instructions. The 2 collections were covered by white paper when not in use to avoid exposing the color patches on the uppermost sheets to the observer

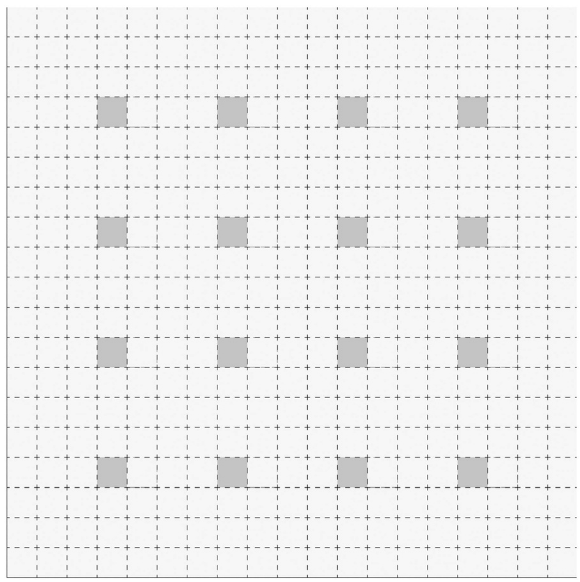

FIGURE 2 An example unit on an answer sheet. It was for 1 color. There were 10 units on each answer sheet. The 4 × 4 shaded small squares denote the 4 × 4 square color patches on a reference sheet. Observers could mark directly on the location of the matching patch (shaded areas), or select a location between 2 or 4 patches (or even outside all patches) on the grids to indicate the matching color fell between, or outside, the appearance of the patches provided

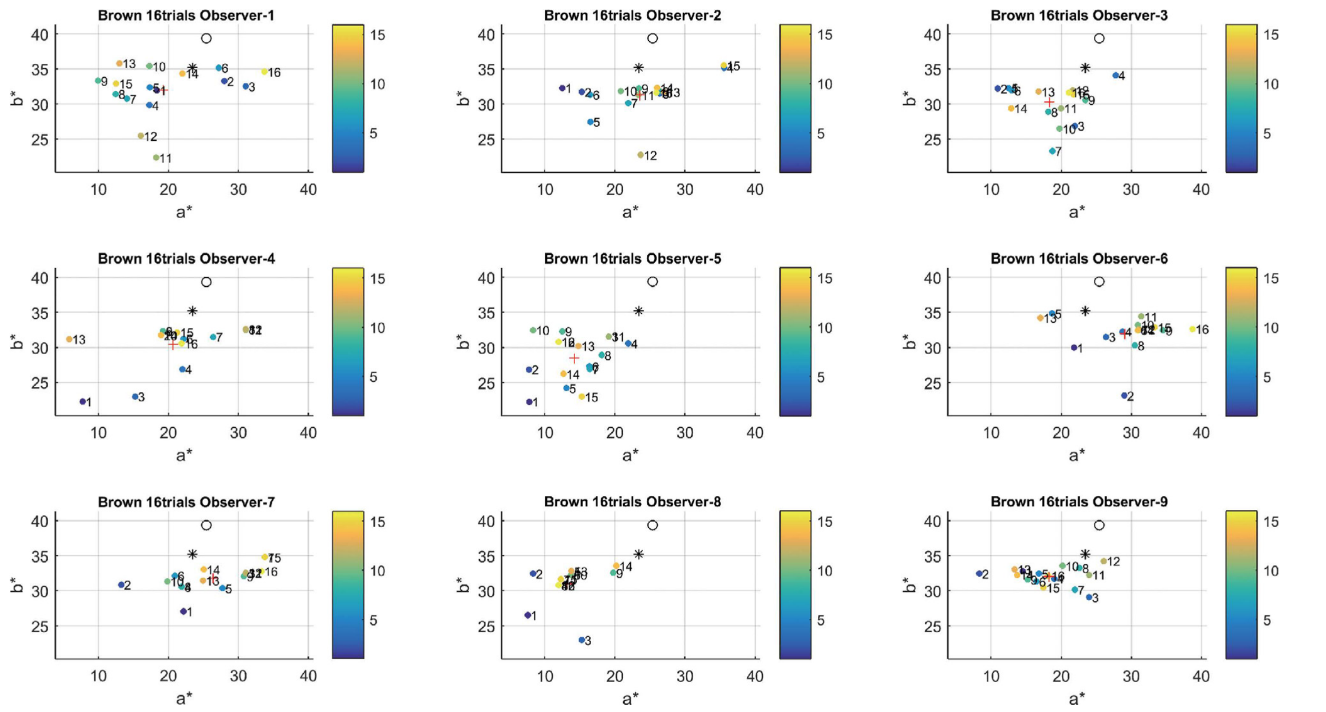

FIGURE 3 The *a***b** distribution plot of matches for 9 observers for the brown color center. The hollow circle sign denotes the test color. 16-trial experimental results are denoted with the color filled circles and trial number. The red "+" sign denotes the mean value (*a**,*b**) of 16 trials for the observer. The black "*" sign denotes the CAT02 prediction result

TABLE 2 The CIEDE2000 standard deviation (SD) of 16-trial results of each observer in the forward phase

Observer	1	2	3	4	5	6	7	8	9	Mean
Dark red	3.16	3.83	4.41	3.54	3.00	2.75	4.23	3.31	3.09	**3.48**
Dark blue	3.67	5.80	2.85	5.39	3.56	2.22	3.46	5.43	3.54	**3.99**
Dark purple	4.24	3.18	2.66	3.39	2.34	4.43	2.62	4.28	3.57	**3.41**
Dark green	3.45	3.64	3.21	3.54	3.31	2.51	2.23	3.53	2.89	**3.15**
Dark brown	4.87	4.12	3.72	4.81	3.46	3.78	3.57	2.66	3.38	**3.82**
Mean	**3.88**	**4.11**	**3.37**	**4.13**	**3.13**	**3.14**	**3.22**	**3.84**	**3.29**	**3.57**

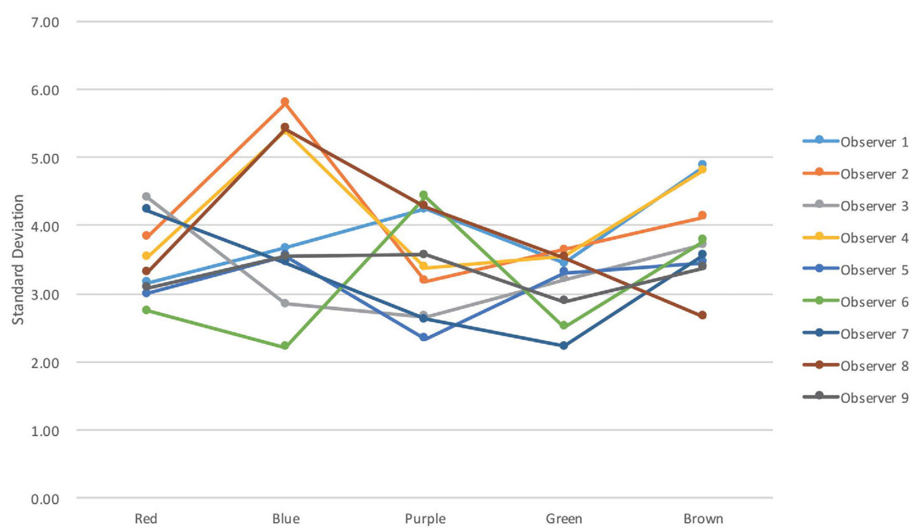

FIGURE 4 The standard deviations of 16-trial results for each observer in the forward phase

TABLE 3 The CIEDE2000 standard error of mean (SEM) of 16 trials for each observer in the forward phase

Observer	1	2	3	4	5	6	7	8	9	Mean
Dark red	0.79	0.96	1.10	0.88	0.75	0.69	1.06	0.83	0.77	**0.87**
Dark blue	0.92	1.45	0.71	1.35	0.89	0.56	0.87	1.36	0.89	**1.00**
Dark purple	1.06	0.80	0.66	0.85	0.59	1.11	0.65	1.07	0.89	**0.85**
Dark green	0.86	0.91	0.80	0.89	0.83	0.63	0.56	0.88	0.72	**0.79**
Dark brown	1.22	1.03	0.93	1.20	0.87	0.95	0.89	0.67	0.84	**0.95**
Mean	**0.97**	**1.03**	**0.84**	**1.03**	**0.78**	**0.78**	**0.81**	**0.96**	**0.82**	**0.89**

had 60 seconds to look at a test sheet and remember the appearance of the 2 test colors. Then the light source automatically switched to daylight and the observer again adapted to it for 2 minutes. Finally, he had 60 seconds to choose the best matches from reference sheets by marking on the answer sheet as shown in Figure 2. They could mark directly on the location of the matching patch (shaded areas), or select a location between 2 or 4 patches (or even outside all patches) on the grids to indicate the matching color fell between, or outside, the appearance of the patches provided. It was considered a round for each test sheet and there were 5 rounds in each session.

After experiments, the results of individual and overall data were calculated. Then intra-observer variability and inter-observer variability of the results were evaluated. The mean values of the standard deviation (SD) and the standard error of the mean (SEM) of individual results were 3.0 and 0.55 CIEDE2000 units. The standard deviation (SD) and the standard error of the mean (SEM) of the overall data were 3.38 and 1.38 CIEDE2000 units, respectively. The research also showed that individual difference in chromatic adaptation exists.

Below is a brief description for experiment II.

2 | EXPERIMENTAL

Experiment II was based on experiment I and with additional changes as follows to explore the reversibility of chromatic adaptation:

- It was a bidirectional experiment (in terms of adapting source transitions) in order to check the reversibility of chromatic adaptation. It included 2 phases. The protocol of each phase was the same as that of experiment I. In the first phase, the chromatic adaptation was from incandescent to daylight. In the second one, the illuminant condition reversed (daylight to incandescent). The 2 light sources were same as those in experiment I. The first phase is denoted as the forward phase and the second is denoted as the reverse phase.
- The number of repetition trials and observers were changed. The repetition trials declined to 16. In light of the results of experiment I, the mean values of the standard error of the mean (SEM) of individual results could be expected to be 0.75 CIEDE2000 units with 16 repetition trials. That can be considered very high precision and enough for the current purposes. Nine observers with normal color vision ability took part in experiment II.
- Five darker colors were chosen for the forward phase of experiment II in order to be different from the 5 light test colors of experiment I. They were dark red, dark blue, dark purple, dark green, and brown, with L^* values from 35 to 52. To allow practical implementation of the experiment, the mean results of the forward phase across 9 observers and 16 trials were adopted as the test colors in the reverse phase.

In total, 1440 estimates were made from the 2 phases.

3 | RESULTS AND DISCUSSION

The spectral reflectance data of each test color patch and reference color patch in the experiments were measured with an X-Rite i1 Pro2 spectrophotometer. Their tristimulus values and CIE $L^*a^*b^*$ values were calculated in terms of the spectral data of the 2 light sources in the viewing booth which were measured with a PhotoResearch PR-655 from a white reference standard. Then the experimental results ($L^*a^*b^*$ and XYZ values) for each observer were computed. The

TABLE 4 The analysis of variance (ANOVA) P-values for 9 observers in the forward phase

Color	Dark red	Dark blue	Dark purple	Dark green	Dark brown
ANOVA	.1651	.0000	.0030	.4104	.1451

TABLE 5 The CIEDE2000 standard deviation (SD) and the standard error of mean (SEM) for overall data in the forward phase

Color	SD	SEM
Dark red	1.78	0.59
Dark blue	2.93	0.98
Dark purple	2.43	0.81
Dark green	3.56	1.19
Dark brown	3.33	1.11

individual and overall data of the 2 phases are shown in Appendices A and B. Figure 3 is the a^*b^* distribution plot of 9 observers for the brown color center. 16-trial experimental results are denoted with the color filled circles and trial number. Their colors help to show the trend of 16 trial results more obviously. When the filled circle is bluish, it is an early trial and when the filled circle is yellowish it is a late trial. The red "+" sign denotes the mean value (a^*,b^*) of 16 trials of the observer. The hollow circle sign denotes the test colors and the black "*" sign denotes the CAT02 prediction point. CAT02 is thought 1 of the 4 best chromatic adaptation transforms so far.[2]

From Figure 3 it can be seen that the mean value of 16 trial results (+) is farther away from the test color (hollow circle) than the CAT02 prediction result (*) for every observer. It is a systematic deviation. Given the precision of the results, it is clear that CAT02 is not an accurate predictor of these experimental data.

3.1 | Reliability test

To test the reliability of the experimental results, intra-observer and inter-observer variability were both evaluated. Additionally, the consistency of the experimental results was tested by the method proposed by Cai et al.

3.1.1 | Intra-observer variability

Standard deviations of 16 trials for each observer and each color in the forward and reverse phases were computed in terms of the formula of the standard deviation except that $(X_i-\bar{X})$ in the formula was replaced by the color difference in CIEDE2000 between the result of each trial and the mean result of 16 trials as shown in Equation 1.

$$SD=\sqrt{\frac{\sum_{i=1}^{n}\Delta E_i^2}{n-1}} \tag{1}$$

The results of the forward phase are shown in Table 2 and Figure 4. From Table 2 it can be seen that the standard deviations of 16 trials of each observer and each color in the forward phase range from 2.2 to 5.8. They are a little bigger than those in experiment I which are from 1.6 to 4.8. It is possible this was caused by the fact that the 5 test colors in experiment II are more difficult to remember than those in experiment I as they are less like categorical focal colors.

The standard errors of mean (SEM) of 16 trials for each observer were also computed and shown in Table 3. They were obtained from the standard deviations in Table 1 divided by 4, that is, the square root of 16, the number of trials. From Table 3 it can be seen that the SEM of each observer approximately range from 0.6 to 1.5 and the averaged SEM across the 5 colors and 9 observers is 0.89. They are also a little bigger than those in experiment I, which are from 0.3 to 0.9. This is due to the slight increase of the standard deviations and the decrease of the repetition number.

Analysis of variance (ANOVA) also shows that 9 observers have significant difference in blue and purple but not in other 3 colors as shown in Table 4 (significant difference exists when the ANOVA P-value is smaller than .05 in terms of 95% confidence interval). Thus, there are some significant inter-observer differences, but not for all colors.

The standard deviations and the standard errors of mean (SEM) of 16 trials for individual observer in the reverse phase are almost like the forward one and are provided in Table 6.

The standard deviations and the standard errors of mean (SEM) of the experimental results across 9 observers and 16 trials for each color in the forward phase were computed and shown in Table 5. The standard deviations vary a bit largely from color to color. The dark red color has the smallest deviation 1.78 and the dark green has the biggest one 3.56.

The inter-observer variability of the reverse phase is similar to the forward one. The averaged standard deviations and the standard errors of mean (SEM) of the experimental results for individual observer and across 9 observers across 5 colors in the 2 phase are all shown in Table 6.

From Table 6 it can be seen that the standard deviations of the results across 9 observers in the forward and reverse phases are 2.81 and 2.56 with a mean of 2.69. They are significantly smaller than 4 CMC (1:1) units (which are similar in magnitude to CIEDE2000 color difference units) which is

TABLE 6 The averaged CIEDE2000 standard deviation (SD) and standard error of mean (SEM) of the experimental results for individual observer and across observers across 5 colors in the 2 phases

Index	Forward	Backward	Mean
SD-individual	3.57	3.87	3.72
SEM-individual	0.89	0.97	0.93
SD-overall	2.81	2.56	2.69
SEM-overall	0.94	0.85	0.90

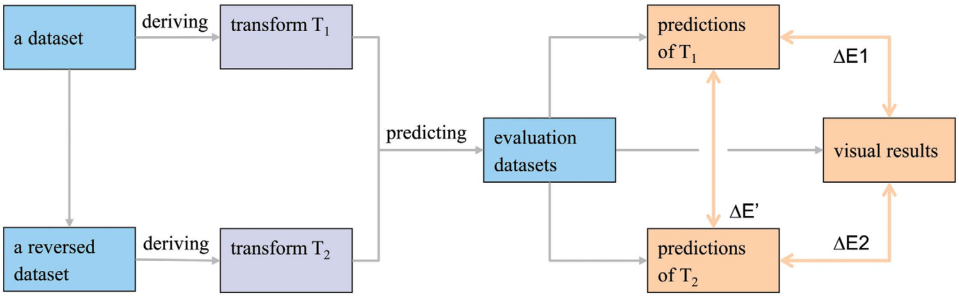

FIGURE 5 The idea of the method to evaluate a corresponding colors data set based on 2 transforms. First a reversed data set is obtained from an original data set. Then 2 transforms T1 and T2 are derived from the 2 data sets, respectively, and applied to predict evaluation data sets. For an excellent data set, the error between the 2 prediction results, $\Delta E'$, should be close to 0

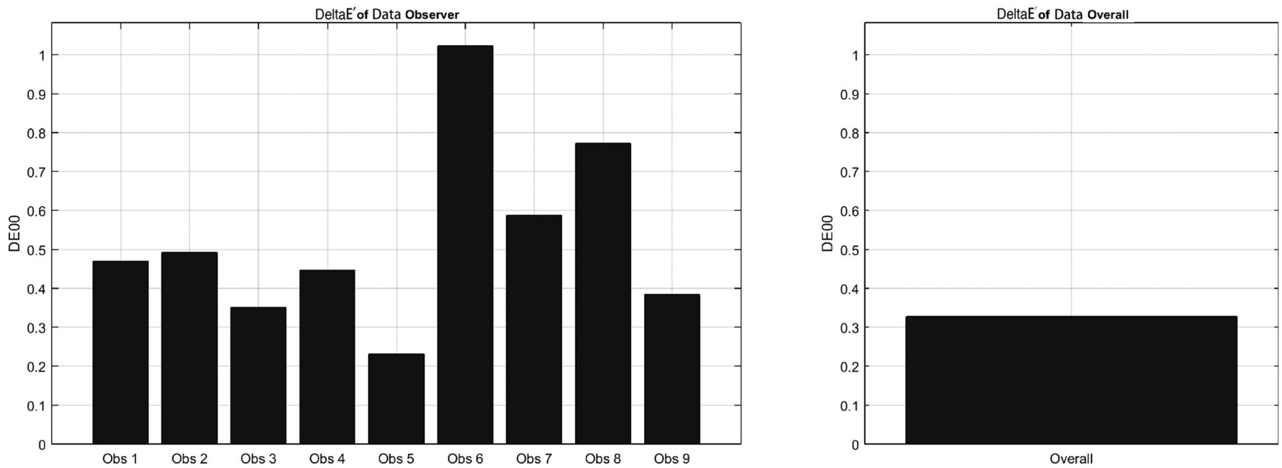

FIGURE 6 $\Delta E'$ of the data from the forward phase for each observer and overall data

found by Kuo et al. (1995) for typical inter-observer variation for studying chromatic adaptation.[2] Thanks to the large number of repetition of each observer, the standard errors of mean (SEM) of the results of individual observer and across 9 observers of the 2 phases are all less than 1.0.

3.1.2 | Consistency test

Cai et al. proposed a method to test the consistency of a corresponding colors data set.[18] Figure 5 shows the idea. A chromatic adaptation transform usually can be derived from a corresponding colors data set. According to Cai's method a second transform can be derived by exchanging the 2 groups of tristimulus values of the data set. Ideally, the observation sequence of the 2 illuminants does not influence the experimental results under complete adaptation condition during chromatic adaptation experiment. So the "reversed" data set should be equivalent to the original one and the second transform should perform equivalently compared with the first one. Hence for an excellent data set, the prediction results of its 2 derived transforms should be close to each other. As a result, the color difference $\Delta E'$ between the prediction results by these 2 transforms can be adopted to test the consistency of the data (under the assumption that an optimized von Kries type model can describe the data). The smaller the $\Delta E'$ is, the better the consistency of the data is.

The color difference $\Delta E'$ in CIEDE2000 between the prediction results by the 2 transforms derived from the data of the individual forward phase and overall data were calculated and shown in Figure 6.

TABLE 7 Data set consistency results $\Delta E_{00}'$ for the 8 excellent data sets selected in Cai's research

Data	Lam and Rigg	Helson	Lutchi	Kuo and Luo
$\Delta E_{00}'$	0.27	0.53	0.30	0.70
Data	**Breneman 6**	**CSAJ**	**Breneman 1**	**Kuo and Luo (TL84)**
$\Delta E_{00}'$	0.66	1.12	1.28	0.67

The current experiment falls well within the best consistency of previous work.

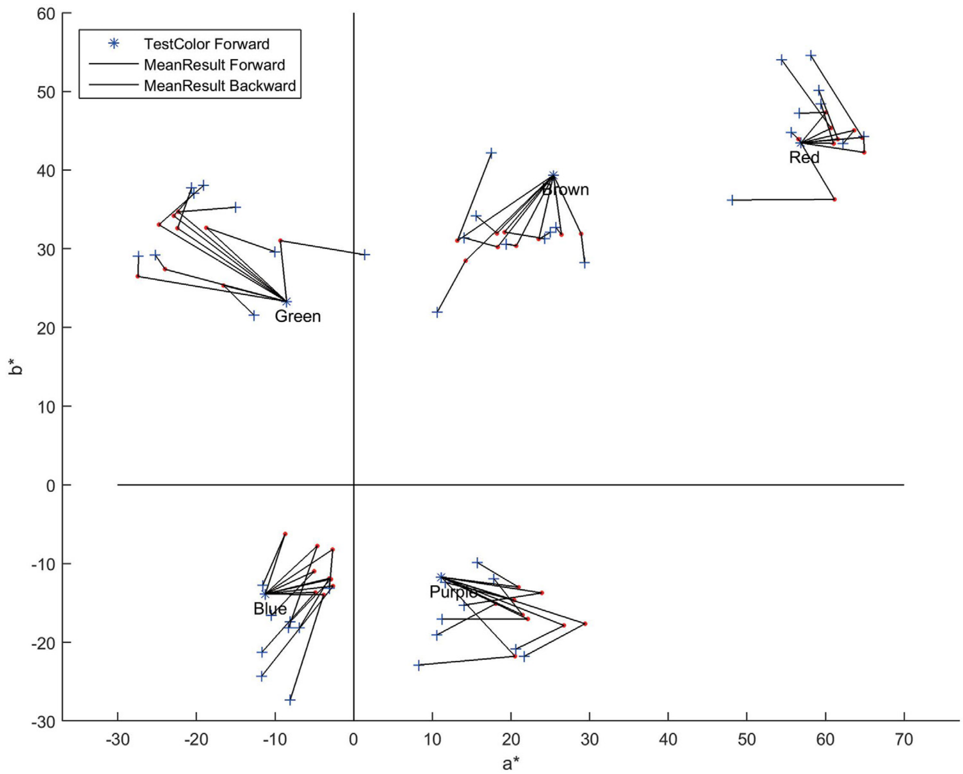

FIGURE 7 The individual chromatic adaptation results of 9 observers for 5 colors in the bidirectional experiments. The asterisk (*) denotes the test colors in the forward phase. The dot (.) denotes the mean results of individuals in the forward phase. The plus sign (+) denotes the transformed individual results of the backward phase [Color figure can be viewed at wileyonlinelibrary.com]

From Figure 6, it can be seen that the $\Delta E'$ of 6 individual data out of 9 data are less than 0.5 and the $\Delta E'$ of the overall data is only about 0.3. Compared with the 8 superior data sets in Cai's research (their $\Delta E'$ are shown in Table 7), they are essentially equivalent with the collection of the best previously reported results.

3.2 | Bidirectional results analysis

3.2.1 | Individual results

In order to check the bidirectional experimental results, the test colors and the individual results of each observer of the bidirectional phases are plotted in the a^*b^* plane in Figure 7. The asterisk (*) denotes the test colors in the forward phase. The dot (.) denotes the mean results of individuals in the forward phase. The plus sign (+) denotes the transformed individual results of the reverse phase. In the reverse phase experiment, each observer actually used the same test color patches. In order to show individual chromatic adaptation results in the figure, the actual results of each individual in the forward phase are adopted as the test colors in the reverse phase. Then the actual results of the reverse phase of each individual were transformed by CAT02 in terms of the actual results of each individual in the forward phase and the actual test colors in the reverse phase to get the individual results of

TABLE 8 The biases between the test colors of the forward phase and the results of the backward phase in terms of CIEDE2000 for each observer and overall data

Observer	1	2	3	4	5	6	7	8	9	Overall
Red	5.12	7.44	7.64	6.64	6.61	7.82	5.19	6.29	6.47	5.96
Blue	9.46	11.32	9.20	9.25	8.81	9.96	9.65	8.89	11.27	9.29
Purple	7.91	6.60	5.28	5.90	4.97	9.89	8.23	4.11	6.88	5.42
Green	8.14	9.38	4.08	3.12	9.63	10.59	5.90	7.69	7.91	5.57
Brown	4.70	3.67	6.33	4.07	9.25	8.10	3.80	6.22	5.54	3.67
Mean	7.07	7.68	6.50	5.80	7.85	9.27	6.55	6.64	7.61	5.98

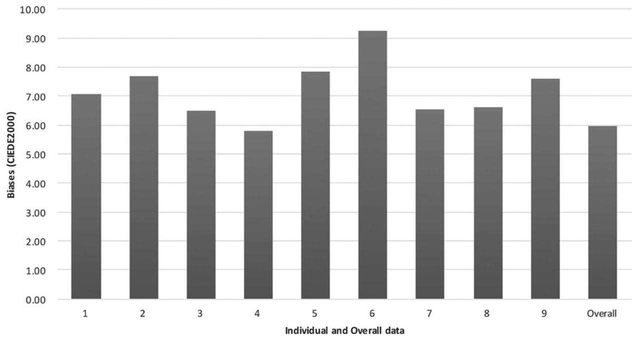

FIGURE 8 The mean biases between the test colors of the forward phase and the results of the backward phase across 5 colors for each individual and for overall data

the reverse phase. As a result, the individual chromatic adaptation results of 9 observers of the bidirectional experiment for 5 colors are shown as in Figure 7.

Ideally, the results of the forward phase could be different from observer to observer but their results of the reverse phase should all be same and identical with the test colors of the forward phase (if one assumes adaptation should be reversible). In other words, the 2 lines denoting the 2 phases should ideally be coincident. But the actual conditions are not the case. From Figure 7, the results of the reverse phase do have a trend to come back to the test colors of the forward phase especially in blue and purple, but are far from the test colors of the forward phase. Furthermore, there are large differences between the 9 observers.

The biases between the test colors of the forward phase and the results of the reverse phase indicate a potential inaccuracy of the experimental data despite their high precision. The biases can be used to evaluate the inaccuracy of corresponding colors data.

The biases in terms of CIEDE2000 for each observer and overall data are computed and given in Table 8 as well as the means. The mean biases across 5 colors for each individual and overall data are plotted in Figure 8. From Figure 8, it can be seen that the largest bias of individuals is more than 9.0 and the least 1 is nearly 6.0. The averaged bias across individuals is 7.2, which seems somewhat large. Given the precision of the experiments, this bias is very significant. It is also worth noticing that these biases are roughly the magnitude of inter-observer variability, which suggests that lack of reversibility could well have been masked in historical corresponding colors data.

It is also noticed that observer 6 has the biggest error in this measure. It agrees with the results in the consistency test in which the $\Delta E_{00}'$ of observer 6 data is the biggest as shown in Figure 4. It shows an agreement of these 2 measures.

3.2.2 | Overall results

The test colors and the mean results across 9 observers of the 2 phases are plotted in the a^*b^* plane in Figure 9.

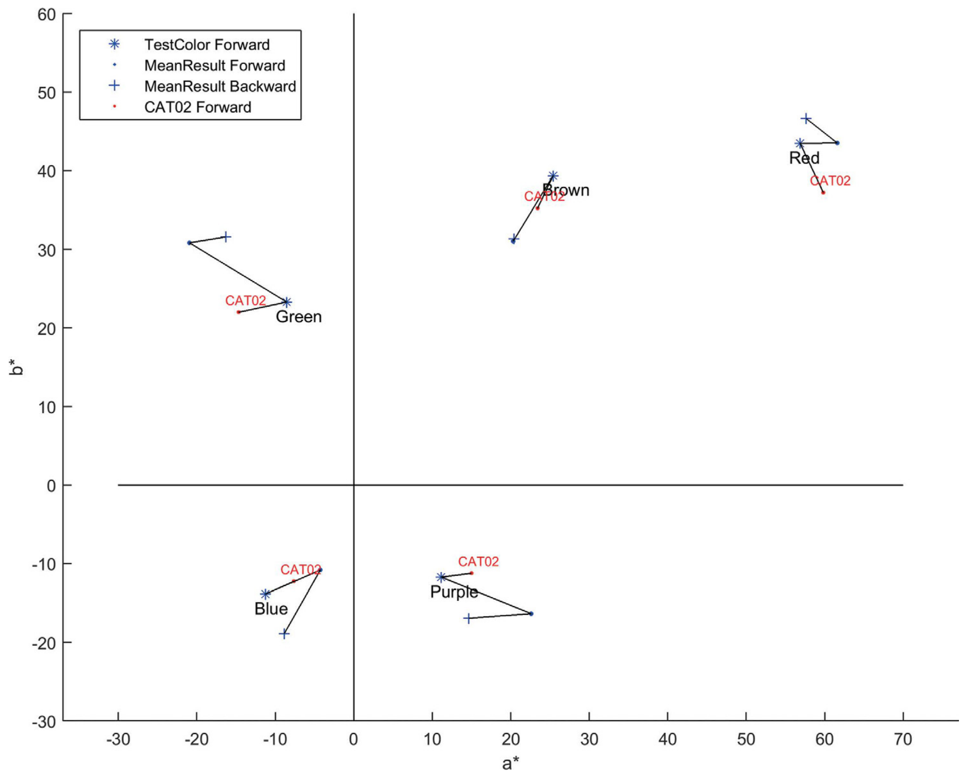

FIGURE 9 The test colors and the mean results across 9 observers of the 2 phases. The asterisk (*) denotes the test colors in the forward phase. The dot (.) denotes the mean results of 9 observers in the forward phase. The plus sign (+) denotes the transformed results of the reverse phase. The prediction results of CAT02 for the forward phase are also denoted

The asterisk (*) denotes the test colors in the forward phase. The dot (.) denotes the mean results of 9 observers in the forward phase. The plus sign (+) denotes the transformed results of the reverse phase by CAT02 in terms of the mean results of 9 observers in the forward phase, the actual test colors in the reverse phase and actual results of the reverse phase. The prediction results of CAT02 for the forward phase are also denoted. The prediction results of CAT02 for the reverse phase are identical to the test colors in the forward phase, of course. Almost all experimental results in the forward phase go significantly further away from the test colors than the CAT02 prediction results. The biases in terms of CIEDE2000 for overall data are given in Table 8 with a mean of 5.98.

The biases for individual and overall data are all large and significant. It is possible that the biases were caused by directional memory distortions during the experiments. An important piece of evidence is that in experiment I the memory errors from the accurate color memory matches after the 2 minutes break averaged across all 6 observers were about 3.5 CIEDE2000 units. The memory distortions had been studied by many researchers and it had been testified that the memory distortions is large.[4,19,20] It was also shown that there were significant memory distortion differences among observers. However, this conclusion cannot be unequivocal at this time and it remains a possibility that human chromatic adaptation is simply not reversible, with some sensory hysteresis or context-based memory distortion responsible.

4 | CONCLUSIONS

This experiment is based on a former experiment and includes 2 phases that include reverse illumination changes. It aims to obtain high precise and individual corresponding colors data, as well as to look into the reversibility of chromatic adaptation.

High precision corresponding colors data of individual and overall observers were obtained from the experiment with significant high replication (16 trials). The CIEDE2000 standard deviations of the results across 9 observers in the forward and reverse phases are 2.81 and 2.56 with a mean of 2.69. The CIEDE2000 standard errors of mean (SEM) of the results of individual observer and across 9 observers of the 2 phases are all less than 1.0. But after the research of the reversibility of the bidirectional procedures it is concluded that the accuracy of the data is to be improved. The mean biases between the test colors of the forward phase and the visual results of the reverse phase for each individual across 5 colors are averaged to 7.2. The value for overall data is nearly 6.0. They are rather large and need to be investigated further. The biases are thought to be caused by memory distortions to some degree but might represent actual failure of reversibility in human chromatic adaptation. Both possibilities, and perhaps others, need to be carefully considered in future research.

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APPENDIX A The mean tristimulus corresponding colors results of 16 trials for the nine observer for the two phases

	The source light source and the test colors in the forward phase			The destination light source and the results in the forward phase (identical to the source light source and test colors in the reverse phase)			The destination light source and the results in the reverse phase		
	X1	Y1	Z1	X2	Y2	Z2	X3	Y3	Z3
Light source	108.1810	100.0000	36.6773	95.2521	100.0000	116.3834	108.1810	100.0000	36.6773
Observer 1	35.3498	19.0146	1.6794	21.0086	11.3878	1.8476	29.2476	15.1643	0.9625
	8.8515	9.5203	5.3357	11.5049	12.8082	21.8403	14.7860	15.6073	9.8241
	9.5817	7.5946	4.1091	10.0627	7.3794	15.3576	13.9710	10.0036	6.7409
	16.9408	17.1939	3.1166	13.1590	17.7130	7.5446	15.9970	18.5230	2.0342
	15.5067	10.5514	0.7691	9.3593	7.5676	2.1118	18.0216	12.6290	1.5107
Observer 2	35.3498	19.0146	1.6794	20.7190	11.1308	1.9511	28.3847	15.0029	0.6541
	8.8515	9.5203	5.3357	11.4504	12.4162	18.3980	16.1630	15.4675	8.0148
	9.5817	7.5946	4.1091	9.6017	7.5345	15.0848	13.8896	10.3046	5.4122
	16.9408	17.1939	3.1166	15.2094	17.6540	8.0114	20.2097	18.4147	2.7707
	15.5067	10.5514	0.7691	9.3143	7.0634	2.0206	16.5863	11.4271	1.2575
Observer 3	35.3498	19.0146	1.6794	19.4468	10.1583	2.7815	24.4203	13.4694	1.3383
	8.8515	9.5203	5.3357	11.5915	12.6021	20.6106	15.2981	15.4975	8.9151
	9.5817	7.5946	4.1091	9.5168	7.3999	15.0246	12.4510	9.9867	6.0738
	16.9408	17.1939	3.1166	14.5102	18.2357	10.0683	17.7658	18.8096	3.6932
	15.5067	10.5514	0.7691	8.9609	7.3045	2.2415	14.1339	11.0113	1.2285

(Continues)

APPENDIX A (Continued)

	The source light source and the test colors in the forward phase			The destination light source and the results in the forward phase (identical to the source light source and test colors in the reverse phase)			The destination light source and the results in the reverse phase		
	X1	Y1	Z1	X2	Y2	Z2	X3	Y3	Z3
Observer 4	35.3498	19.0146	1.6794	20.0071	10.4695	1.8941	28.2723	14.1458	0.7253
	8.8515	9.5203	5.3357	11.3164	12.5655	18.3164	15.2533	15.4878	9.0741
	9.5817	7.5946	4.1091	9.5535	7.5477	13.5240	13.4425	10.2212	5.0653
	16.9408	17.1939	3.1166	13.7276	17.7026	7.4868	17.5757	18.1084	2.6716
	15.5067	10.5514	0.7691	9.4180	7.4328	2.2923	15.8950	11.6858	1.3916
Observer 5	35.3498	19.0146	1.6794	20.3820	10.4416	1.7572	28.9245	14.0460	1.0216
	8.8515	9.5203	5.3357	11.3831	12.6936	20.2085	15.0286	15.6469	8.8181
	9.5817	7.5946	4.1091	9.8298	7.4645	13.6797	13.1268	10.1875	5.8864
	16.9408	17.1939	3.1166	13.1289	17.9884	9.2724	15.2389	18.5927	2.8120
	15.5067	10.5514	0.7691	8.2931	7.1323	2.3790	13.4325	10.8977	1.8275
Observer 6	35.3498	19.0146	1.6794	20.3874	10.3120	1.8038	27.8335	14.0450	0.5521
	8.8515	9.5203	5.3357	11.6450	12.6159	21.1114	14.5805	15.4122	10.4396
	9.5817	7.5946	4.1091	9.6807	7.7255	17.9076	12.2027	10.1611	7.1957
	16.9408	17.1939	3.1166	12.6584	18.0378	9.4971	14.8456	18.5690	2.8221
	15.5067	10.5514	0.7691	11.0018	7.8903	2.3050	19.3795	12.8780	1.7660
Observer 7	35.3498	19.0146	1.6794	20.3893	10.2813	2.0503	31.9914	15.4450	1.1466
	8.8515	9.5203	5.3357	11.5310	12.5677	20.5311	15.4445	15.4377	9.0559
	9.5817	7.5946	4.1091	10.1169	7.1296	14.8061	13.8027	9.7362	6.7538
	16.9408	17.1939	3.1166	13.1196	17.6518	6.8215	16.7988	18.2848	2.1972
	15.5067	10.5514	0.7691	10.2022	7.4923	2.1196	17.1094	11.7175	1.2694
Observer 8	35.3498	19.0146	1.6794	19.1258	10.5337	1.9101	27.2927	14.1068	0.9572
	8.8515	9.5203	5.3357	10.9657	12.7969	17.8893	15.0316	15.8400	8.1122
	9.5817	7.5946	4.1091	9.3488	7.4389	14.0696	12.6607	10.1131	5.3943
	16.9408	17.1939	3.1166	12.7850	17.6859	7.3564	16.1757	18.4182	1.9928
	15.5067	10.5514	0.7691	8.4167	7.3528	2.1632	15.9261	11.9814	0.8236
Observer 9	35.3498	19.0146	1.6794	19.9036	10.4711	1.9431	28.2481	14.0874	0.7894
	8.8515	9.5203	5.3357	11.5907	12.7381	21.9426	15.1998	15.4002	11.1583
	9.5817	7.5946	4.1091	9.3651	7.6983	14.6877	12.8463	10.4071	6.6408
	16.9408	17.1939	3.1166	13.0720	17.6855	7.0384	15.9125	18.3792	2.0644
	15.5067	10.5514	0.7691	8.8344	7.2004	1.9626	14.5526	11.1463	1.0963

APPENDIX B The overall data across nine observers and 16 trials from the two phases

	The source light source and the test colors in the forward phase			The destination light source and the results in the forward phase (identical to the source light source and test colors in the reverse phase)			The destination light source and the results in the reverse phase		
	X1	Y1	Z1	X2	Y2	Z2	X3	Y3	Z3
Light source	108.1810	100.0000	36.6773	95.2521	100.0000	116.3834	108.1810	100.0000	36.6773
Color 1	35.3498	19.0146	1.6794	20.1522	10.5762	1.9932	28.2782	14.3974	0.9040
Color 2	8.8515	9.5203	5.3357	11.4421	12.6449	20.0942	15.1957	15.5316	9.2604
Color 3	9.5817	7.5946	4.1091	9.6751	7.4798	14.9046	13.1539	10.1256	6.1285
Color 4	16.9408	17.1939	3.1166	13.4856	17.8172	8.1219	16.7142	18.4416	2.5526
Color 5	15.5067	10.5514	0.7691	9.3112	7.3818	2.1773	16.1024	11.7045	1.3468