Color memory match under disparate viewing conditions

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Abstract

A color memory experiment with 5 colors (red, green, blue, yellow, and Caucasian skin color) was carried out. The color patches, shown on an LCD monitor, was memorized under a given viewing condition. The mixing of the memory color was then done first under the same viewing condition, and subsequently under other two altered viewing conditions. The conditions were different in the background and surround parameters. The color appearance model CIECAM02 was then used to predict color attributes under the altered viewing conditions. The lowest color memory shift in hue attribute was found for the red color. CIECAM02 seemed to have some limitation in colorfulness and chroma attribute prediction, for colors viewed on a black background. The result show, that the color attributes prediction in color memory experiment was not successful.

Introduction

In practical applications, color reproductions are typically viewed under different conditions, such as different light source, luminance level, and background. To predict color attributes for different conditions, several color appearance models have been proposed [1]. Between observations of color in two different conditions, shorter or longer time delay is mostly present [2, 3, 4, 5, 6]. Therefore, color memory is one of the additional factors, which can influence color predictions; however, this is rarely taken into account in color appearance research.

After a brief literature review on color memory, we present the aim and setup of our experiment. Then the results are presented and discussed in the following section, before we conclude in the last section.

Color memory

To identify systematic memory shifts, several experiments have been carried out in the past. The historical progress and overview of color memory experiments has been thoroughly described by Bodrogi [7, 8]. In a general description of a color memory experiment, first the color memory cue is given to the observer. It can be an abstract cue, in case of a long-term memory investigation, or a memory cue, in case of a short-time color memory investigation. Both types can be given with or without image contexts. As the second step, the observer has to find or recreate the memorized color. There are three general methods of obtaining the memorized color: Mixing, selecting or deciding [9, 10]. The method of mixing is based on the adjustment of the parameters of the actual color patch (e.g. RGB, LCh). In the selection method, the observer has to select the color from a set of color patches. The third method is based on the decision of the observer, whether the actual color is his memory color or not.

A short-term color memory shift can be explained by a cognitive effect, using the concept of exaggeration, focality and typicality. It is also reported that color memory shift is not related to perceptual artifacts (e.g. changes in viewing situations) [7, 8, 9].

In a color memory experiment, the observer tends to categorize the perceived original color and inclines to remember only the category (the cognitive color). The color memory shift usually tends towards the long-term memory colors of familiar objects or toward focal colors. From the CIE report on Cognitive color [10] it is recommended that a clear distinction should be made between cognition and perception. Perceived color consist in any combination of chromatic and achromatic content and has three continuous perceptual attributes (hue, colorfulness and brightness). Color perception is classified into a category or categories in visual processing. Cognitive color is one of the discrete set of these categories.

Review of color memory experiments

In D'Ath's color memory experiment [11], the memory of 12 hues of CIE UCS diagram was studied. His results show that blue-green color was difficult to remember and also difficult to name. The hue of the purple color was easy to remember and easy to name. The standard deviation of chromaticity difference was similar to the one obtained by Selinger [12], which investigated short-term and long-term memory shift of fourteen colors. In his results, the mean standard deviation for 1s delay was significantly lower than mean standard deviation for 5s delay. Minimal standard deviations were found for wavelengths, which represent blue and yellow color.

An investigation of color memory of ten Munsell chips in three delay times shows, that mean color difference increased with time delay, but colors after 24 hour were not worse. The largest contribution was related to the increase of chroma [5, 13]. Under illuminant D65, the most difficult color to remember was yellow. The easiest colors to remember were oxide red and orange. The hue did not follow a recognizable pattern. Light colors were remembered as lighter, and dark colors as darker. This effect is identical with the findings of Newhall, reported by Bodrogi in overview of color memory experiments [7, 8].

In the PhD thesis of Bodrogi [8], observers had to memorize the color of uniform color patches inside a black frame placed in a photorealistic image (memory cue with image context). After a short time, the observer had to select the color they memorized from 15 uniform patches on a gray background. In the second part or the experiment, the original color was simply a uniform color patch on a middle gray background, without any image context. To see the pure result of the memory shift, he tried to achieve the same viewing condition for photo and geometric images. In the result, he estimated prototypical colors for Caucasian skin, sky colors, compared green colors for foliage, grass plant and snow. The standard deviations of the hue shifts were usually greater in case of photorealistic images than for standalone color patches. For the standalone patches the largest shift was observed in chroma for sky, skin and plant color groups. The results show, that in short-term, color memory of the standalone color patches becomes less accurate when the chroma of the original stimuli increases. The lightness shift increased with an increase in the lightness of the original color in case of photorealistic images.

In a later study by Bodrogi and Tarczali [14] a technique of color mixing was used. The observers had to memorize color of a uniform color patch surrounded by a black frame within a photorealistic image. After a while they had to adjust lightness, hue and saturation of a gray color patch, within a blurred version of the original image, or only the color patch with a black frame within a gray background. From the results, the authors were able to establish constant hues for every investigated color group. For sky colors, observers tend to agree on hue more than on saturation. For skin photos the opposite effect was observed. For green colors, there was a weak tendency to agree on saturation more than on hue.

In a decision color experiment [15] observers were asked to decide, if the decided color is the same as the original color. The original colors, Caucasian skin, green grass and blue sky were used as color center in simultaneous matching and memory matching, with and without image context. The largest variability was found for the case of uniform color patches and the lowest for simultaneous matching, except for Caucasian skin, where the smallest variation was found in case of a photorealistic image with memory color deciding. Similar results were obtained in a mixing technique [16], where the variability of the chosen color in case of standalone patches was greater than in case of grayscale photos.

In another study made by Pérez-Carpinell [17], the long-term memory of 8 familiar objects was investigated. The observers were asked to select a color associated with a given name of an object. The selection was done from 10 color samples placed on a gray cardboard. The selection was made under D65 and A light sources. Watermelon, yellow lemon, pink rose and purple aubergine colors did not change dominant wavelength under D65, red tomato and yellow lemon under A source as well.

A more interesting study using two light sources D50 and A was carried out by de Fez et al [6]. The reference sample was shown under D65 source. Then, the observer had to select a memory color from Munsell charts under illuminant A. In comparison with the result obtained by their experiment under the same illuminant [5], the remembered lightness behaves differently, depending on the matching illuminant. In the case of the same illuminant the lightness of the selected color depends on the lightness of the original color. In the case of an illuminant change, there is no common trend in this attribute.

Aim

From the literature overview it can be seen that color memory experiments have been carried out under the same viewing condition [12, 14, 15, 16], or under two different light sources [6, 17]. In color memory experiments no one has performed experiments with different backgrounds or surround parameters. On the other hand, the color appearance models are also based on color memory data [19, 1]. The memory experiment is most similar to the real life situation. It is useful to obtain corresponding data for cross-media color reproduction [3, 4], for a change of surrounding parameters. It has also been used as a tool to evaluate and compare data in color memory experiments [18].

This project aims to evaluate color memory match, obtained under simply specified viewing conditions, which will vary in surround and background parameters only. Since color memory shift is assumed not to be related to the perceptual artifacts [7, 8, 9], it will be investigated, how well CIECAM02 can predict colorimetric values in such experiments. The second goal is to find out, whether there will be differences between mixing memory color under different conditions, and if so, how large. Furthermore this paper deals with the question of whether a color appearance model can be used for evaluation of the experiment.

Experimental Setup

The main experiment was designed to obtain colorimetric data of mixed memory colors under 3 different conditions. Therefore, the experiment consisted of 3 parts, each part being carried out in different days. The original colors were shown in all three parts under the same condition. In the first part, the observers had to mix memorized color under the same condition as they had seen the original colors. In the second and third parts, the condition of mixing was different from the original one. All three parts were done in exactly the same way; there was only a change in conditions before mixing in the second and third parts. The selected conditions and corresponding parameters are shown in Table 1.

The participants were acquainted with the mixing of the colors by adjusting RGB channels and they tried to mix some color examples before the experiment started. 15 observers with a normal color vision participated in the experiment. Each of them was first adapted to the dim laboratory condition for 5 minutes by playing a simple Snake game; where on a middle gray background a white snake body was moving in order to follow a black dot. After that, they were asked to memorize 5 colors which were shown separately in a sequence on a middle gray background. The choice of colors was based on the work of Bodrogi and de Fez [5, 7, 13], regarding the display gamut and expected color memory shifts. Table 2 shows the RGB values with corresponding Lab values obtained from XYZ using a white point measured under the same condition. The distance of observers' eyes was approximately 80 cm, the size of a color square was 6.7 cm (250 px), which makes 4.8 degrees angular subtense. Each color was shown for 10 sec, and between the colors a gray patch was also shown for 10 sec. In the second part, the background was changed to black and the laboratory light was set to a maximal intensity before they were asked to mix the memory color. In the third part, the background was changed to white and the laboratory light was turned off.

Table 1. Overview of used combination and measured values for different conditions

	original color condition							
	background	surround	T (K)	L_{dw} (cd/m^2)	Yb	L_{sw} (cd/m^2)	Sr	L_a (cd/m^2)
Part 1	Gray	min. ambient (dim)	6620	132,7	29,42	4,761	0,04	26,54
Part 2	Gray	min. ambient (dim)	6620	132,7	29,42	4,761	0,04	26,54
Part 3	Gray	min. ambient (dim)	6620	132,7	29,42	4,761	0,04	26,54
	mixing condition							
	background	**surround**						
Part 1	gray	min. ambient (dim)	6620	132,7	29,42	4,761	0,04	26,54
Part 2	black	max.ambient (avg)	6596	135,8	2,949	141,9	1,04	27,16
Part 3	white	no ambient (dark)	6632	133,1	133,1	0,269	0	26,62

T- white point color temperature, L_{dw}- luminance of the device white, Y_b- Y value of the background, L_{sw}- luminance of the surround white, S_r- surround ratio, L_a- luminance of the adaptation field

Table 2. The RGB and L*a*b* values of the original colors

Color	R	G	B	L*	a*	b*
Cauc. skin	200	160	150	65,06	17	14,36
Green	105	140	70	45,87	-32	38,94
Blue	105	150	180	52,86	-9,8	-25,9
Red	160	75	75	35,13	48,5	30,11
Yellow	215	190	80	74,4	-1,9	66,86

In all the parts, the observers played the Snake game again for 3 minutes before mixing, which also served as adaptation time after a change of the condition has been made.

After this time, the observers had to mix the memorized colors to obtain the best match. The middle gray was chosen as the initial actual color for each of the 5 mixed memory colors. Written instructions were accessible, so they did not need to remember the order of the colors. The observer was not limited in time for mixing colors. The time delay between the first shown and the first mixed color was 5 minutes. The adjusted RGB values were recorded and later measured under the same condition as they were mixed, and XYZ values were recorded (2 deg. observer).

The second experiment was a simultaneous match on one screen. The original color shown on a gray background was mixed by adjusting RGB channels of the patch shown on the same screen but with a black or white background. The distance between two backgrounds was set to 80px (approximately 1,5cm), what was also the same distance to the border of the screen. This space was black. Both backgrounds were framed by 6px white line. The laboratory light was set to minimum (dim condition). The environment characterization was not identical with the memory experiment, but it was approximately the same. In the simultaneous match experiment 15 observers with a normal color vision participated. This group of observers was familiar with RGB color mixing.

For the experiment we used a *Dell 2407WFP* LCD display, connected to a PC running Windows XP, with an *ATI RADEION X600* graphics card. The monitor color temperature was set to 6500K and the luminance to 120cd/m^2, using Eye-One software and spectrometer device from GretagMacbeth. The parameters for the viewing conditions were measured by the spectroradiometer Minolta CS-1000 (Table 1). The size of the screen was approximately 67,7x42,3 cm. The monitor resolution was 1920x1200 px. The monitor with a black frame was placed in a neutral surrounding environment. The temperature of the ambient laboratory light source F8 was approximately 5100K, measured in maximum possible luminance.

The recorded XYZ values were separated for each color. Each set of XYZ values of the mixed color consist of 15 observers. For each color and each observer, the *L*a*b** coordinates were computed. As the second step, the XYZ of colors mixed under dark and average (avg) condition, were transformed to the dim condition, using a forward and inverse CIECAM02 color appearance model [1, 20, 21]. The input surrounding, background, parameters in the forward model were corresponding values for dark, respectively average condition. The input parameters for the inverse model were values of the dim condition (see Table 1.). The new X'Y'Z' values, for colors mixed under dark and average conditions, were transformed to a new set of *L*a*b** coordinates.

As the third step, all XYZ values were transformed to the CIECAM02 parameters. The background, white point and surrounding parameters used for transformation corresponded to the condition, in which the color was mixed/observed. In order to evaluate, the coordinates of the CAM02-UCS space were computed. [22]. The J_m coordinate represents the lightness attribute and the coordinates a_m b_m are computed from the hue and colorfulness attributes. The mean values of the color coordinates were computed in the last step, after all transformations.

Results and discussions

The illustration of original colors and colors mixed under dim condition are shown in CIELAB a*b*-diagram (Figure 1a) and in CAM02-UCS space (Figure 1b). These figures show that the distribution of colors mixed by 15 observers is wider in colorfulness attributes than in hue attributes, except for yellow, where the agreement of a hue attribute is less accurate The most inaccurate attribute was lightness (Figure 1c). The CAM02-UCS diagram should be better to show the real distribution in parameters, due to a better perceptual uniformity. The ellipses shown in the figures define a 90 % of confidence interval.

To investigate how well the CIECAM02 transformation predicts coordinates in CAM02-UCS space, the mean values of the coordinates are shown in Figure 2a, and 2b. The dim coordinates are some sort of reference memory color, because mixing of this color was done under the same condition as the original color. Because the original color was always shown in the same condition, the observers should recall the same memory color in all the three parts of the experiment. Under all three mixing conditions, they should mix the color with the same visual sensation, which corresponds to their memory color.

Dark and average mixing conditions both resulted in higher brightness. The increase of brightness of the patches, with the black background under average condition, is attributed to the maximum luminance of the ambient light. The influence of simultaneous contrast (black background) seems to have lower influence on brightness of the mixed samples. Under dark conditions, white background has a huge effect on brightness. The largest change is for darker colors, which are red and green (Figure 2a).

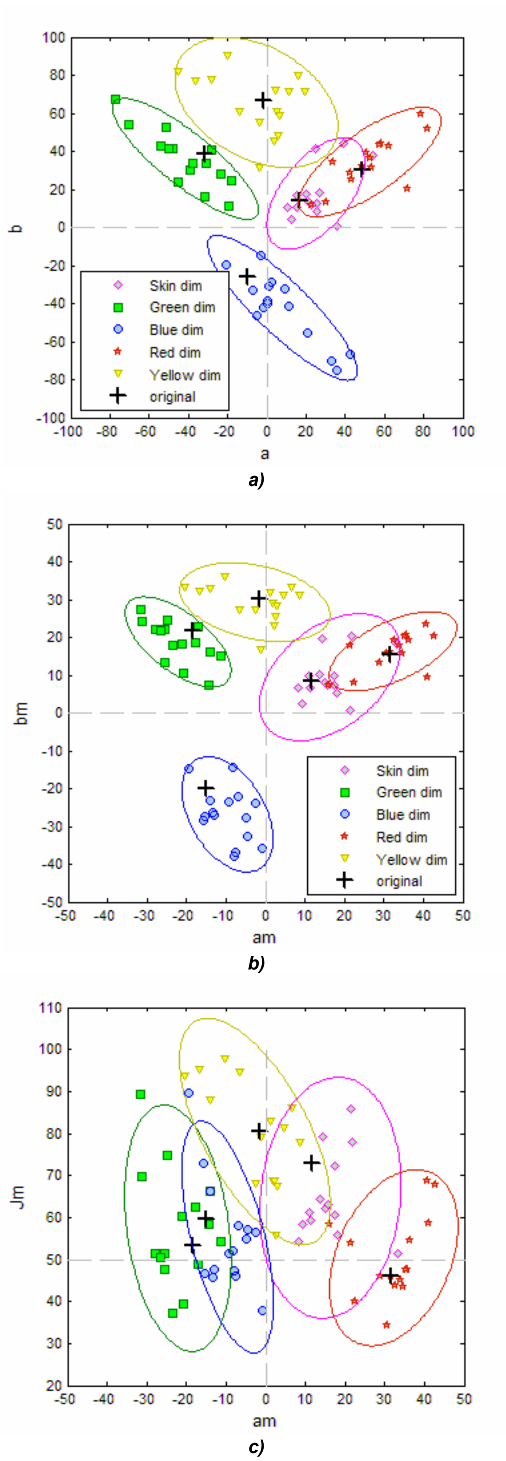

Figure 1.
a) The CIELAB diagram of original colors and colors mixed under dim condition in a-b plane;
b) The original colors and colors mixed under dim condition in a_m-b_m plane of CAM02-UCS space;
c) The original colors and colors mixed under dim condition in a_m-J_m plane of CAM02-UCS space

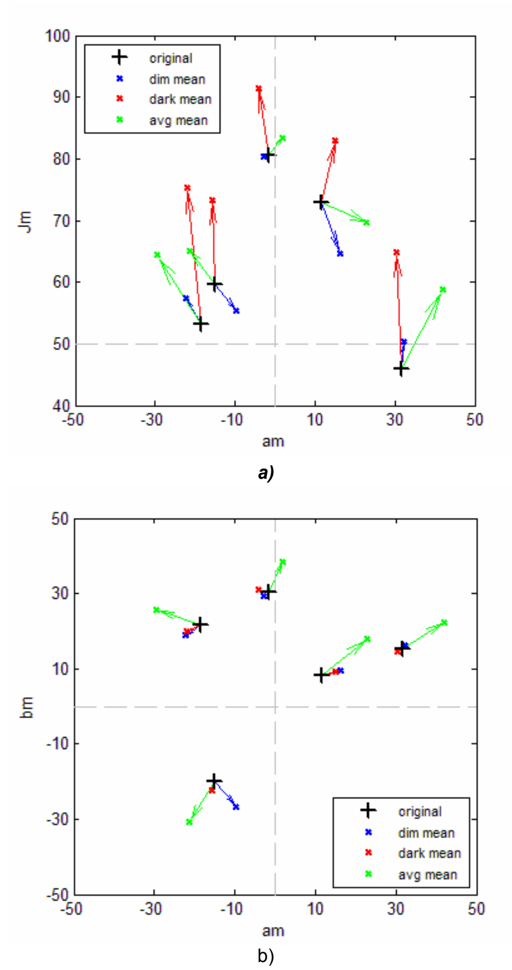

Figure 2.
The mean shifts of mixed colors in CAM02-UCS space in a_m-J_m plane (a); and in a_m-b_m plane (b)

This evaluation shows that for our purposes, CIECAM02 does not provide a reliable prediction of lightness, hue, and colorfulness attributes. The model seem not to be functional in the selected conditions, even though they were really simple, and all parameter measurements and computing were done precisely, according to the published instructions [1, 20, 21]. The model predicted some of the appearance phenomena, but did not approximate perceptual attributes computed from the data obtained in our experiment. The mean values are in Figure 2b shown in a_m-b_m plane.

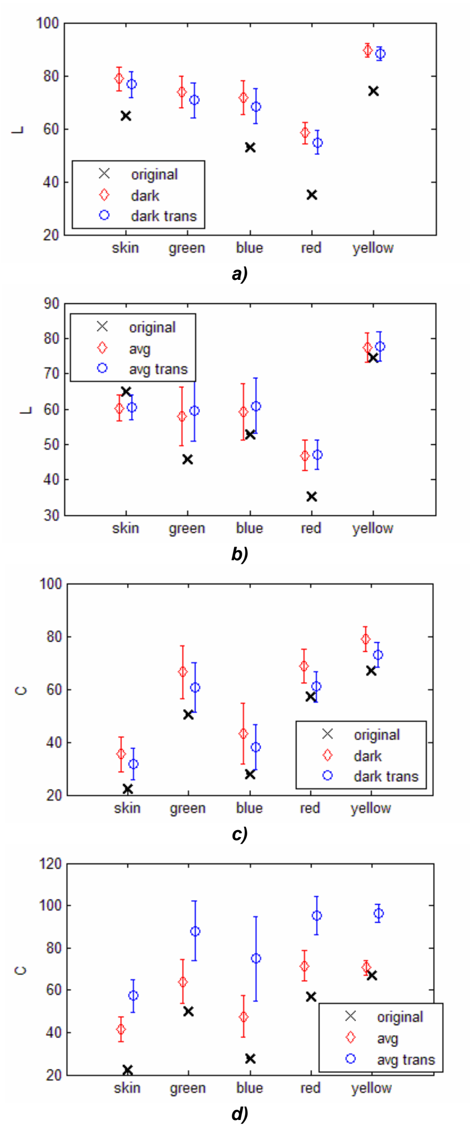

Figure 3.
a) The error bar of CIELAB lightness attribute of colors mixed in DARK condition, before and after transformation
b) The error bar of CIELAB lightness attribute of colors mixed in AVERAGE condition, before and after transformation
c) The error bar of CIELAB chroma attribute of colors mixed in DARK condition, before and after transformation
d) The error bar of CIELAB chroma attribute of colors mixed in AVERAGE condition, before and after transformation

Table 3. The color difference (dE) and attribute differences (dL, dC, dh) in CIELAB space

dE	Skin	Green	Blue	Red	Yellow
dim	21,24	24,60	31,40	19,78	26,52
dark	25,59	38,27	33,54	29,43	22,51
avg	22,95	30,51	33,12	23,11	15,14
dL	Skin	Green	Blue	Red	Yellow
dim	-9,14	5,14	-4,19	4,37	0,72
dark	13,75	27,94	18,89	23,20	15,15
avg	-4,85	12,16	6,23	11,71	3,05
dC	Skin	Green	Blue	Red	Yellow
dim	9,46	5,23	17,55	6,10	1,03
dark	13,15	16,32	15,41	11,62	11,90
avg	19,12	13,72	19,86	14,52	3,74
dh	Skin	Green	Blue	Red	Yellow
dim	-6,72	9,85	24,87	0,95	1,58
dark	21,27	6,91	3,02	-1,20	2,92
avg	3,28	8,91	3,87	2,50	-4,69

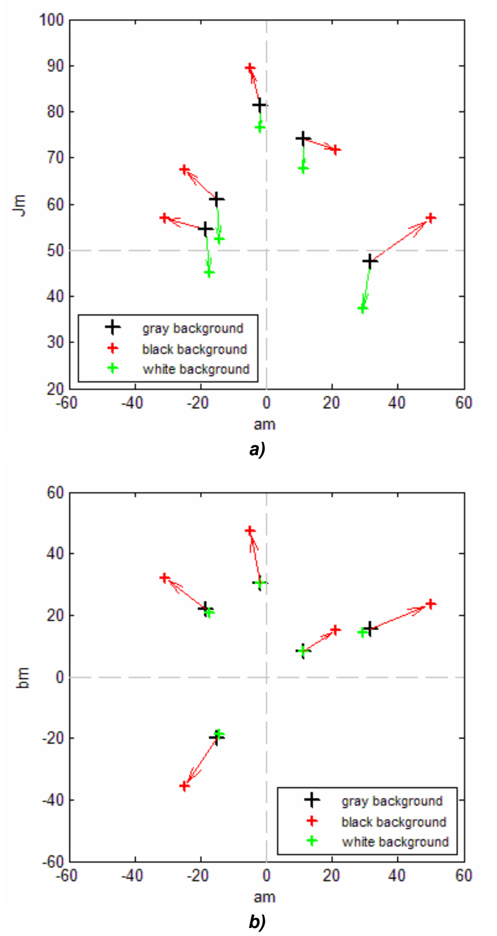

Figure 4.
The mean values of color coordinates mixed on different background in simultaneous match experiment shown in a_m-J_m plane (a), and in a_m-b_m plane (b)

The forward and inverse CIECAM02 model was also used to compute new colorimetric values of colors mixed under dark and average condition. The comparison of color attributes before and after CIECAM02 transformation is illustrated in error bars shown in Figure 3. It can be clearly seen, that the CIECAM02 forward and inverse transformation moved the coordinates of colors mixed under dark surrounding and with white background in a good direction. The background caused a darker perception of the perceived colors, and therefore target colors had to be mixed brighter. In this case the CIECAM02 forward and inverse transformation performed a better prediction of the attributes chroma, and slightly better prediction in the attribute lightness. In the second case, where the colors were mixed under the conditions of an average surrounding and black background, the prediction failed in chroma attribute,. The a*b* parameters computed from new X'Y'Z' are moved to the extreme values. Some of them were moved to the value of more than 140. The error bars shown in Figure 3 represent the 90 % of confidence interval. From these results is not clear which factor has the main influence in the unsatisfactory chroma transformation. The comparison of memory match with simultaneous match enables us to specify the main factor in unsatisfactory chroma prediction. The simultaneous match was obtained with background variations only, under the same surrounding condition. However, the results obtained by the CIECAM02 forward transformation, which have the same type of the background (Figure 4b), show almost identical to the results obtained from memory matching (Figure 2b). The coordinates of the colors, mixed with black background were moved towards the same direction of colorfulness increasing, and the colors mixed on white background had good prediction.

The lowest distributions and smaller difference of hue factor (CIELAB) for red color, was observed in all three conditions. A larger hue difference of the green color is found for all three conditions. A higher blue hue was mixed under dim conditions, but the hue of blue color mixed under average and dark conditions do not have a larger change from the original color. CIELAB color differences and attribute differences are shown in Table 3. In case of the yellow color mixed under dark and average conditions, the distribution in all attributes is almost half of the distribution under dim condition.

Conclusion

The colorimetric values of color memory mixing under three viewing conditions were obtained. The CIECAM02 was used to eliminate perceptual artifacts of different conditions. The appearance model slightly improved the prediction of the colorimetric attributes in case of white background conditions. From our experiment it seems to be obvious, that CIECAM02 has some limitations to predict especially the attribute colorfulness of the color perceived on black background. The largest inter-observer variability was in the color attribute lightness. The best agreement was for the hue attribute, especially for the red color. The color memory match using additional separated experiments with only one parameter change should lead to more complex evaluation of color appearance model prediction in case of such memory experiment However, the CIECAM02 model did not predict the color attributes obtained by memory match under disparate viewing condition, under assumption that color memory shift is not related to viewing situations.

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