What Can We Learn from a Dress with Ambiguous Colors?

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Abstract: We performed objective spectroradiometric measurements on an LCD image of the recently famous Tumblr dress which is typically perceived by people as blue/black or white/gold. The average ± standard deviation of the CIELAB coordinates was as follows: For a set of 33 points in the areas considered as blue/white, $L^* = 46 \pm 6$, $C^*_{ab} = 33 \pm 6$, *and* $h_{ab} = 282 \pm 3°$, *and for a set of 36 points in the areas considered as black/gold,* $L^* = 29 \pm 6$; $C^*_{ab} = 10 \pm 4$; $h_{ab} = 16 \pm 34°$. *Initially, this first set of values has low variability and corresponds to a blue color, whereas the second set of values has a very large hue-angle range, including points which can be considered as both gold and black colors. We also performed spectrophotometric measurements on an original model of this dress, and, assuming D65 illuminant and CIE 1931 colorimetric standard observer, the average results were* $L^* = 26$, $C^*_{ab} = 39$, *and* $h_{ab} = 289°$, *and* $L^* = 10$, $C^*_{ab} = 1$, *and* $h_{ab} = 290°$ *for the blue/white and black/gold points, respectively. We discuss the influence of different factors on the blue/black and white/gold perceptions of different people, including observers' variability in color-matching functions, Bezold–Brücke and Abney effects, background influence, and illumination assumptions. Although more research on the effect shown in this dress is needed, we think that from this example we can learn that objects do not have specific colors; that is, color is a human perception, and many times the answer of the human visual system is not simple and relies on assumptions of unknown, and variable, origin.* © 2015 The Authors Color Research & Application Published by Wiley Periodicals, Inc., 40, 525–529, 2015; Published Online 25 May 2015 in Wiley Online Library (wileyonlinelibrary.com). DOI 10.1002/col.21966

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INTRODUCTION

On February 26, 2015, a user of the social networking service Tumblr raised an unusual polemic on the internet as people strongly disagreed over whether the colors of a dress in a specific image were black and blue or white and gold.[1] Some people reported being able to see both colors at different times or even swap the colors of the dress at will. #Thedress began trending on Twitter, along with other hashtags, and in the first week after the image surfaced, more than 10 million tweets mentioned the dress.

Although many different theories have circulated on the reasons for the different colors perceived in this dress image by different people, missing were objective color

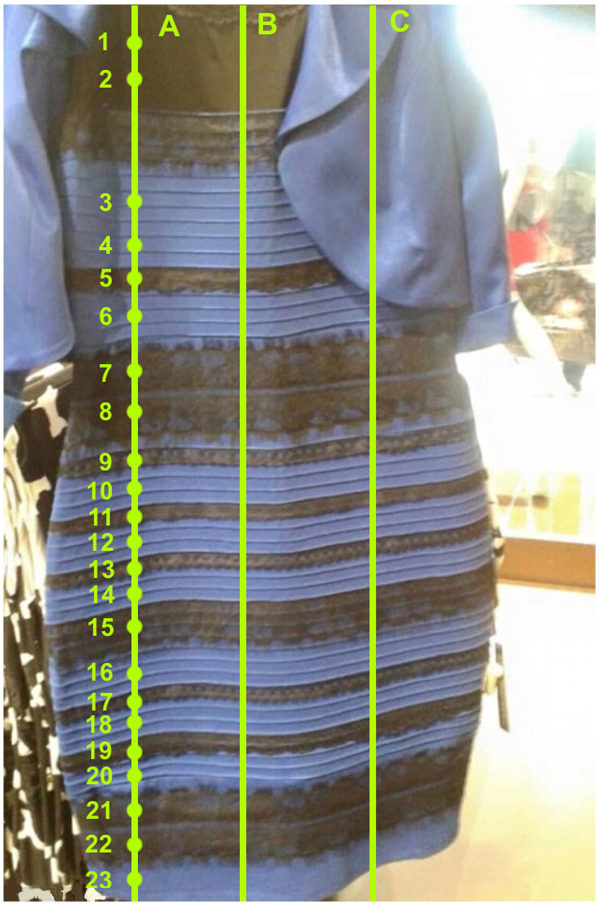

Fig. 1. The Tumblr dress with ambiguous colors.

measurements both on the image of the dress and also on the dress itself (a product from the retailer Roman Originals). This may be useful information in a first approach to further understanding the perceptual phenomena involved. The next section provides the results of a set of such measurements, with the corresponding discussion. Obviously, different pictures of this dress may have different colorimetries and appearances, as a consequence of different deliberate or incidental modifications of contrast and/or display primaries. In this sense, although the internet phenomenon was 100% about the colors of the image, it is also relevant to know the results of color measurements on the real dress assuming different illuminations to perhaps investigate the unusual imaging configuration and lighting that led to the ambiguous image.

It is well known that human color perception is a complex phenomenon, and the polemic around the color of the image of this dress seems just an example of such complexity. Color scientists may be surprised by the effect shown in this dress because it seems not to fold along the accustomed perforations of opponent-color theory. Without trying to be exhaustive, in the last section of this article, we discuss some potential factors affecting in more or less degree the different colors perceived by people in this peculiar image, whereas we conclude that at least some aspects of the problem, such as how observers infer illumination color in limited images, remain open to additional research.

EXPERIMENTAL MEASUREMENTS

Color Measurements on an Image of the Dress

We used a JPEG image of the viral Tumblr dress[2] with 461×300 pixels, which was displayed on a typical sRGB LCD monitor (HP w255hc). A set of $23 \times 3 = 69$ points placed on the blue/white or on the black/gold areas of such image were selected for color measurements as shown in Fig. 1. Spectroradiometric measurements were performed in a completely dark room using a CS 2000 Konica Minolta spectroradiometer using the 0.2° measuring field, the distance between the head of the spectroradiometer and the screen of the monitor being about 90 cm. The monitor warmed-up for 30 min before the start of measurements. We assumed the CIE 1931 colorimetric standard observer for color measurements, as usually done in experiments using digital images,[3] and the reference white used for transformations to CIELAB[4] was the white area just outside of the image in Fig. 1, with coordinates $x = 0.3378$, $y = 0.3058$, and $Y = 103.1$ cd/m^2; and a correlated color temperature of about 5200 K. The spectroradiometer was always focused on the same position at the center of the monitor screen, and the image was moved using a precise vertical scroll control to measure the different points (Fig. 1). In this way, the lack of color uniformity of the monitor screen can be avoided. The tabulator key was used to move the image horizontally to measure the points on lines A–B–C. As the strips of the dress are not completely horizontal, the points with the same number at lines A–B–C were slightly displaced in the vertical orientation, in such a way that the measurement field was always placed on areas which can be called either blue/white or black/gold. Although the colors of the points 1A, 1B, 2A, 2B, 5A, and 5B are black/gold, those of the points 1C, 2C, and 5C must be considered as blue/white. Overall, we measured 33 blue/white and 36 black/gold points as shown in Fig. 1.

The main results of our color measurements in the C^*_{ab}-L^* and h_{ab}-L^* planes are shown in Fig. 2 for the blue/white and black/gold points of the dress. The average ± standard deviation of CIELAB color coordinates was $L^* = 46 \pm 6$, $C^*_{ab} = 33 \pm 6$, and $h_{ab} = 282 \pm 3°$ for the blue/white points, and $L^* = 29 \pm 6$, $C^*_{ab} = 10 \pm 4$, and $h_{ab} = 16 \pm 34°$ for the black/gold points. Figure 2 shows that the blue/white and black/gold points have a considerably different range of L^* and C^*_{ab} values, the blue/white points being considerably lighter and more chromatic than the black/gold ones. Figure 2 also shows that for the blue/white points the CIELAB hue-angles are in tightly defined range from -83 to $-68°$ (or, equivalently, from 277 to 292°), which corresponds to colors usually designated as blue, and agrees with people reporting that the true color of this dress is blue and not white. However, the hue-angles for the black/gold points are in a considerably wide range from -56 to $+74°$, with most points in the interval 0–90°, which corresponds to the red–yellow region. This fact, together with the relatively small L^* values of the black/gold points, could certainly lead to the perception of gold or brown hues.

On the other hand, the spread of a given set of N colors with respect to its average can be measured[5] using the

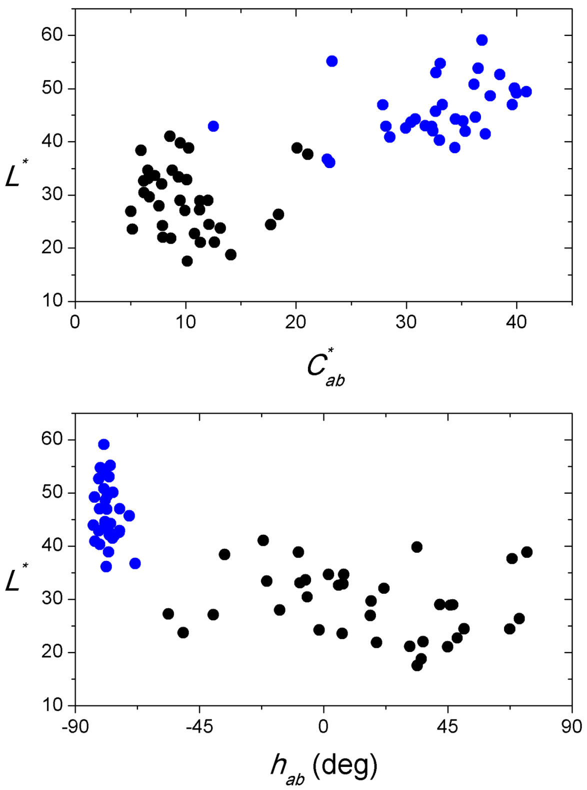

Fig. 2. Color coordinates for the 33 blue/white (blue symbols) and 36 black/gold points (black symbols) measured in Fig. 1, distinguishing the results in CIELAB planes C^*_{ab}–L^* and h_{ab}–L^*.

so-called "mean color difference from the mean," *MCDM*, defined by the next equation:

$$MCDM = \frac{\sum_{i=1,N} \left[\left(L_i^* - \overline{L^*}\right)^2 + \left(a_i^* - \overline{a^*}\right)^2 + \left(b_i^* - \overline{b^*}\right)^2 \right]^{1/2}}{N} \quad (1)$$

where the bars indicate the arithmetical mean of color coordinates. In our current case, the MCDMs were 7.2 and 8.6 CIELAB units for the blue/white and black/gold points, respectively, indicating that color variability is higher for the black/gold points as it should be expected from a detailed observation of Fig. 1, as well as from the results shown in Fig. 2. The numerator in Eq. (1) is a summation of CIELAB color differences, and each one of these color differences can be split in its three components: lightness, chroma, and hue differences. On the average, for the blue/white and black/gold points, the main variability was in lightness, with two very similar percentages of 50 and 49% of the MCDM values, respectively. However, the percentage of hue difference was considerably different for the blue/white and black/gold points, with values of 11 and 33%, respectively. This is connected with the very different hue-angle variability of these two sets of points shown in Fig. 2.

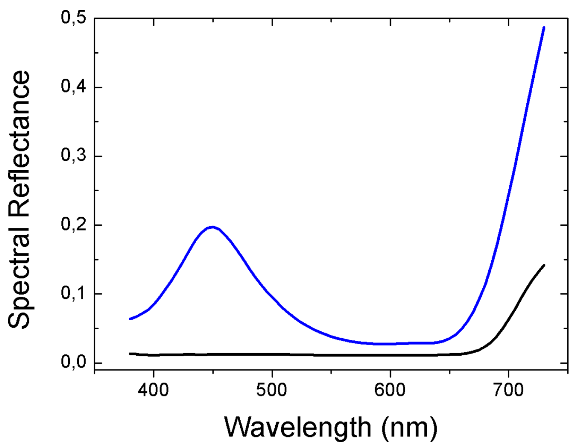

Fig. 3. Average spectral reflectance factors measured on blue/white and black/gold points on a original model of the dress from Roman Originals.

Color Measurements on the Dress Itself

We have bought an original model of the Tumblr dress and measured spectral reflectance factors at five different blue/white and black/gold points on the dress, using a GretagMacbeth Spectrolino spectrophotometer with 45/0 geometry. The average results of these measurements are shown in Fig. 3. Typically, these two spectral reflectance factors, correspond to object colors usually designated as blue and black, but we cannot forget that, properly speaking, objects have no color (i.e., color depends on the lighting source, among other factors). Assuming the illuminant D65 and the CIE 1931 colorimetric standard observer, the average CIELAB coordinates were $L^* = 26$, $C^*_{ab} = 39$, and $h_{ab} = 289°$ for the blue/white points, and $L^* = 10$, $C^*_{ab} = 1$, and $h_{ab} = 290°$ for the black/gold points. In addition, assuming the illuminant A and the CIE 1931 colorimetric standard observer, the average CIELAB coordinates were $L^* = 24$, $C^*_{ab} = 39$, and $h_{ab} = 268°$ for the blue/white points, and $L^* = 10$, $C^*_{ab} = 1$, and $h_{ab} = 314°$ for the black/gold points. It is not surprising that these color coordinates are different from those previously found for the spectroradiometric measurements of an image of this dress, because the true dress and the image can be, and will almost always be, in fact very different. In particular, we can see that lightness L^* is considerably lower in the real dress under D65 or A illuminant than in the measured image on the LCD monitor. Even more, we can note that for the real dress the ratio of the L^* values for the blue/white and black/gold points is 2.6–2.4, whereas in the case of the monitor image this ratio was 1.6. Therefore, for this dress the visual contrast between blue/white and black/gold areas is different in the real dress and in the image we have considered.

DISCUSSION

In connection with the different colors perceived by observers in this dress, which is the main point raising discussions on social networks, the next points can be addressed:

1. Here, we are using the designations of colors by names (color naming), which may be considered a fuzzy technique. In fuzzy approaches, a given color may have a membership degree in more than one color category. It is also possible that the physical color stimuli in this particular image produced color perceptions that fell at, or near, color name boundaries and thus adding to the confusion among observers.
2. Although in many situations color is the most important attribute to define the appearance of a material, certainly it is not the only one. Color usually interacts with gloss and translucency attributes. In the current dress, we can perceive some transparencies in the black/gold areas (e.g., points 7 and 8 in Fig. 1), which may have an influence in our color measurements as well as in the overall visual perception. On the other hand, nowadays materials with gonioapparent effects (i.e., change of color with illumination/viewing angles) are frequently used in automotive[6] and other industries. It cannot be completely discounted that materials of this dress have some gonioapparent properties.
3. We know that there is a relatively wide range within the category of observers considered as with normal color vision (normal trichromats). For instance, CIE TC 1-82 is currently studying the dependence of color-matching functions with the size of the visual field and observers' age.[7] The color-matching functions of different real observers may be considerably different, in particular in the blue region, and ongoing research aims to quantify this for practical applications.[8,9] There is no evidence to suggest that this fact plays an important role in the current problem.
4. Changes in lightness induce changes in hue (Bezold–Brucke effect) and saturation (Abney effect). Pridmore[10] has reported that these effects are not only present in monochromatic unrelated colors, but also in related colors of usual objects. In our case, considering the monitor image, the measured luminance in cd/m^2 for the blue/white points changed between 9.1 and 27.1 (about a factor 3), and between 2.4 and 11.9 for the black/gold points (about a factor 5). Consequently, some change in perceived hue can be produced, in particular for the black/gold points. In addition, changing the pupil size of the observer, the retinal illuminance also changes, and this may influence the perceived hue in the current case as reported by some observers perceiving the dress as more clearly blue/black when they use smaller pupil sizes.
5. It is well known that the background behind a given homogeneous color sample may have a very strong influence on its perceived color as shown in the so-called simultaneous contrast or induction effect. Light/dark backgrounds induce darker/lighter colors in the corresponding samples. Also, red/green or blue/yellow backgrounds induce the corresponding opponent hues in the samples. This effect may be present in some extent in the current case although the current situation (Fig. 1) is not identical to the one suggested by some people.[11]
6. The assumption of a specific illuminant (i.e., the effect known as discounting of illuminant or approximate color constancy) seems to be the most important factor in the problem we are considering here.[12,13] If we interpret the illumination of the dress as bluish and dim, it is perceived as white and gold, but if the illumination is yellowish and bright, the dress is perceived as blue and black. Cleverly, or perhaps because of poor photography, the picture of this dress lacks of sufficient information on what is the true illumination in the current case. It has been reported that the images of this dress with appropriate context to understand the illumination show that the dress is clearly perceived as blue/black[12] as suggested by the measurements performed by us on the real dress. In the right side of the picture outside the dress (see Fig. 1), the average luminance is very high, even slightly higher than the reference white assumed by us, which leads to some L^* values slightly higher than 100. On the other side, the black and white area on the left bottom region outside the dress shows a considerably lower lightness. Although the phenomenon of discounting the illuminant is well understood and modeled,[13] what remains a mystery to be explored is the cause of differential illumination estimations by different observers of this image. Understanding those mechanisms and making predictive illumination estimations for different observers would be a major contribution to color science. Fortunately, viewing situations with such divergent responses are rare.
7. It is also possible that the appearance of this dress changes with the visual display used to view it, as a consequence of the change in color appearance with luminance levels and size of the stimuli.[14,15] Visual displays may also have some angular dependence, in such a way that in some cases it can be said that the dress has some different colors when viewed at different viewing angles on the same screen. As mentioned before, it should also be noted that confusion often exists between judging the color of the dress itself and the color of the image of the dress. This is mainly due to the extremely overexposed image that was published along with its unique spatial context that afforded no information about the illumination. It is extremely unlikely that different photographs of the same dress would be so visually interesting.

CONCLUSIONS

Traditional color science[13] states that, in a first approach, objects have a perceived color which is the result of three main factors (lighting source, object properties, and human visual system), as indicated, for example, in the traditional definition of tristimulus values *XYZ*.[4] Properly, it must be considered that objects do not have a specific color, but a color which may change with the lighting source, background behind samples, and so forth. It must be said that color is a unique human perception, and the problem considered here is a good example of this fact. The complexity of the human visual system is another unquestionable fact. The discussions raised in vision community by the perceived colors of this dress (e.g., more than 140 messages on CVNET in 10 days) show such complexity. We think that multiple reasons can be given to explain the different perceived colors of this dress, the measurements and comments addressed in the current communication are only a preliminary approach and source of objective data for further analyses. Currently, *Journal of Vision* intends to publish a special issue on the perceived color of this dress.

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