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Stripping #The Dress: The importance of contextual information on inter-individual differences in colour perception

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Abstract

In 2015, a picture of a Dress (henceforce the Dress) triggered popular and scientific interest; some reported seeing the Dress in white and gold (W&G) and others in blue and black (B&B). We aimed to describe the phenomenon and investigate the role of contextualization. Few days after the Dress had appeared on the Internet, we projected it to 240 students on two large screens in the classroom. Participants reported seeing the Dress in B&B (48%), W&G (38%), or blue and brown (B&Br; 7%). Amongst numerous socio-demographic variables, we only observed that W&G viewers were most likely to have always seen the Dress as W&G. In the laboratory, we tested how much contextual information is necessary for the phenomenon to occur. Fifty-seven participants selected colours most precisely matching predominant colours of parts or the full Dress. We presented, in this order, small squares (a), vertical strips (b), and the full Dress (c). We found that i) B&B, B&Br, and W&G viewers had selected colours differing in lightness and chroma levels for contextualized images only (b, c conditions) and hue for fully contextualized condition only (c), and ii) B&B viewers selected colours most closely matching displayed colours of the Dress. Thus, the Dress phenomenon emerges due to interindividual differences in subjectively perceived lightness, chroma, and hue, at least when all aspects of the picture need to be integrated. Our results support previous conclusions that contextual information is key to colour perception; it should be important to understand how this actually happens.

Keywords: #TheDress, Internet dress, context, visual colour illusion, colour perception

Introduction

The online picture of a dress (henceforth, the "Dress") evoked a phenomenal interest in early 2015. Online, people could not agree whether the colour combination of the Dress was white and gold (W&G) or blue and black (B&B) (Holderness, 2015). The actual dress from which the Dress picture was taken was manufactured as royal blue with black horizontal stripes (Wallisch, 2017). The ambiguous Dress picture, on the other hand, displayed very different colours to royal blue and black (for CIE Lab coordinates of the Dress see Melgosa, Gomez-Robledo, Isabel Suero, & Fairchild, 2015). The B&B perceivers could not believe that the W&G perceivers saw the same picture and vice versa. Yet, these two perceptions emerged even when people were in the same place at the same time looking at the same monitor (Gegenfurtner, Bloj, & Toscani, 2015). Furthermore, although the colour combination perception seemed to generally remain stable across time, for some individuals, the perception switched between B&B and W&G colour combinations (Chetverikov & Ivanchei, 2016; Lafer-Sousa & Conway, 2017; Lafer-Sousa, Hermann, & Conway, 2015; Vemuri, Bisla, Mulpuru, & Varadarajan, 2016).

The interest in the Dress phenomenon has somehow abated in the public domain, but remains significant to scientists as the scientific contributions including but not limited to a special issue in the *Journal of Vision* highlight. These authors were facing a new visual (colour) illusion (Brainard & Hurlbert, 2015) – an experience when a true source of a stimulus differs from what is perceived (Corney & Lotto, 2007). The ambiguous Dress picture is an interesting visual illusion to study. Unlike some other visual illusions (e.g., simultaneous brightness contrast illusion, Lotto & Purves, 1999), the ambiguous Dress picture does not evoke the "misleading" perception of colours in the same way for all people. The ambiguous Dress picture has been argued to resemble a specific class of visual illusions called bi-stable (or multi-stable) visual illusions (Chetverikov & Ivanchei, 2016; Lafer-Sousa & Conway, 2017; Lafer-Sousa et al., 2015), because it can be perceived in different, changing colour combinations (B&B, W&G). In the case of some bi-stable illusions, perceivers can train to more or less spontaneously switch between different perceptions or even see both of them simultaneously (e.g. see a duck and a rabbit; McManus, Freegard, Moore, & Rawles, 2010). This is not the case for the ambiguous Dress picture, where the change in perception arises spontaneously and only to some viewers (e.g., Lafer-Sousa et al., 2015). In the case of other visual illusions, perceivers may see no solution at all or see several contradictory solutions at the same time (e.g., Mooney faces, Carbon, Grüter, & Grüter, 2013). Many of these visual illusions arise due to prior perceptual experience, knowledge or expectations, which may lead perceivers to seeing one, several, or no possible interpretations.

In the initial Internet survey of about three million respondents, 68% of the respondents indicated seeing the ambiguous Dress picture as W&G and 32% of the respondents as B&B in a forced-choice situation (Holderness, 2015). Subsequent studies reported a higher proportion of W&G viewers (Dixon & Shapiro, 2017; Mahroo et al., 2017; Moccia et al., 2016; Wallisch, 2017; Witzel, Racey, & O'Regan, 2017), a higher proportion of B&B viewers (Chetverikov & Ivanchei, 2016; Lafer-Sousa et al., 2015), or an equal split between the two viewer types (Aston & Hurlbert, 2017; Chetverikov & Ivanchei, 2016; Hesslinger & Carbon, 2016; Karlsson & Allwood, 2016; Schlaffke et al., 2015; Vemuri et al., 2016; Winkler, Spillmann, Werner, & Webster, 2015) using forced-choice and free naming paradigms. In studies that went beyond the possibility of two viewer types, mainly using free-naming paradigms to assess the colours of the ambiguous Dress picture, an intermediate variant of the Dress perception emerged – participants reported seeing the Dress as blue and brown/gold (B&Br) (Aston & Hurlbert, 2017; Lafer-Sousa et al., 2015; Mahroo et al., 2017; Wallisch, 2017; Witzel et al., 2017). Subsequently, it has been suggested that the Dress perception follows a continuum ranging from white to blue and gold to black rather than resulting in discrete categories of either a B&B or W&G perception (e.g. Gegenfurtner et al., 2015).

The possibility that all people perceive the same colours on the ambiguous Dress picture, but name them differently (e.g., very light blue may be named "white" or "blue") has largely been ruled out by colour matching studies (Aston & Hurlbert, 2017; Chetverikov & Ivanchei, 2016; Gegenfurtner et al., 2015; Lafer-Sousa et al., 2015; Toscani, Gegenfurtner, & Doerschner, 2017; Witzel et al., 2017). Common to these studies, participants matched the ambiguous Dress picture colours to colours on computerized or physical colour-matching tools. A consistent result across studies indicated that B&B viewers overall match darker colours than W&G viewers. These perceptual differences support the notion that the differences in reported Dress colours go beyond naming differences and reflect genuine perceptual differences. Colour can be perceptually defined as having three components (colour appearance parameters) – hue (what a laymen refer to as colour: “red”, “yellow”, “green”), chroma (how vivid the colour is), and lightness (how light the colour is; Hunt & Pointer, 2011). These colour parameters are intuitively comprehensible and interpretable. Previous studies did not interpret colour matches to the ambiguous Dress picture from the angle of hue, chroma, and lightness (Aston & Hurlbert, 2017; Chetverikov & Ivanchei, 2016; Lafer-Sousa et al., 2015; Witzel et al., 2017), but they could bring certain insight into how viewers’ perception differs when confronted with the ambiguous Dress image.

Contextualization might play a role in the colour perception of the ambiguous Dress picture. By showing the same picture information, but in a decontextualized way (e.g. cutting the picture in pieces, scrambling), information processing about the surroundings (and, by inference, illumination source) would be disrupted. As the Dress illusion is likely to emerge from the integration of the contextual information on the ambiguous Dress picture, decontextualization should reduce differences in perceived colours on the ambiguous Dress picture between viewer types. Hesslinger and Carbon (2016) provided first evidence for this possibility. These authors cut the ambiguous Dress picture into squares with varying size and scrambled them. They then asked participants to report how blue each scrambled image as well as the original ambiguous Dress picture appeared from looking *not blue at all* to *very blue*. They showed that B&B viewers reported the ambiguous Dress picture being very blue while W&G viewers reported it being not blue at all. As the scrambled square sizes decreased, the difference between B&B and W&G viewers decreased in terms of reported "blueness" of the stimulus. Hence, low degree of contextual information of the ambiguous Dress picture made everyone perceive the colours of the ambiguous Dress picture in a similar way.

Taking into account the published literature, we here report on two studies we performed right after the appearance of the ambiguous Dress picture online. When we spotted this picture, we were, as probably most of our colleagues, intrigued by this phenomena. We tested whether individual differences in the ambiguous Dress image perception persisted in stimuli progressively lacking the contextual richness to understand how much contextual information is necessary for the phenomenon to occur. If the illusion persisted with little contextual information, differences in the ambiguous Dress perception might be driven by lower level factors rather than the different assumptions about illumination. Firstly, four days after the picture's appearance, we conducted a classroom survey to assess the prevalence of the different colour perceptions as a function of demographic variables and subjective illumination interpretations. In a subsequent laboratory study, we wanted to test if and how participants' colour perception changes when systematically adding contextual information of the Dress. We were interested in such potential changes as a function of the different subjective "perception" groups.

Participants were invited to partake in a study on colour perception (the ambiguous Dress was not mentioned). In this fixed order, participants saw parts of the ambiguous Dress picture and then the full, contextualized image. We asked participants to use a computerized colour picker and match their prevalent colour impression for three Dress-related stimuli that varied in the amount of contextual information: isolated *patches* taken from the blue/white regions and the black/gold regions of the ambiguous Dress picture, *strips* along the vertical axis of the ambiguous Dress picture and the ambiguous Dress picture shown *in full* (Figure 1). While the *patches* condition provided reduced information about the surrounding context of the ambiguous Dress as well as eliminated information about the pattern of the ambiguous Dress picture, the *strips* condition preserved information about the ambiguous Dress pattern but reduced surrounding contextual information. Thus, we could investigate: 1) colour matches of the Dress colours and how they differed between viewer types; 2) the role of degree of decontextualization of the ambiguous Dress picture; and 3) the differences in colour parameters between displayed and matched colours of the ambiguous Dress picture.

To be able to report results conveying subjective perception, we broke down participants' colour matches into three perceptual attributes of colour (i.e., hue, chroma, and lightness) and tested whether any of these attributes differed between self-reported colour perception when seeing the full ambiguous Dress picture. Accordingly, we used participants' reported colour perception to subsequently allocate them to Blue and Black (B&B) and White and Gold (W&G) viewers, and also to the repeatedly described group of Blue and Brown (B&Br) viewers. Indeed, in contrast to notions that the ambiguous Dress picture perception is bimodal (Chetverikov & Ivanchei, 2016; Drissi Daoudi, Doerig, Parkosadze, Kunchulia, & Herzog, 2017; Vemuri et al., 2016), the emergence of the B&Br viewer group supports independent reports of a continuous phenomenon (Aston & Hurlbert, 2017; Gegenfurtner et al., 2015; Witzel et al., 2017). It seems that the perceptions of the ambiguous Dress picture ranges from white to blue, and from gold to black. In line with this continuum idea, we analysed results as a function of a linear variation between viewer types and expected that B&Br viewers' colour matches would fall between the matches of B&B viewers and W&G viewers.

Based on previous studies, we hypothesised that lightness of matched colours would differ between self-reported viewer types: B&B viewers would select darker colours than W&G viewers (Aston & Hurlbert, 2017; Chetverikov & Ivanchei, 2016; Gegenfurtner et al., 2015; Lafer-Sousa et al., 2015; Toscani et al., 2017; Witzel et al., 2017). We also expected to find some differences in hue and chroma between viewer types (Aston & Hurlbert, 2017; Chetverikov & Ivanchei, 2016; Lafer-Sousa et al., 2015; Witzel et al., 2017). Because these previous studies analysed colour matches using different colour models, we could not use their results to formulate more precise predictions. For contextualization, we could expect that decontextualization disrupts the Dress illusion because 1) different viewer types have different interpretation of the background on the ambiguous Dress picture (Chetverikov & Ivanchei, 2016) and 2) scrambling of the ambiguous Dress picture reduces the difference in perceived "blueness" on the ambiguous Dress picture between viewer types (Hesslinger & Carbon, 2016). If background information was more important, we could expect the differences between viewer types to disappear in both decontextualized conditions (*patches* and *strips*). If information about the Dress pattern was more important, we could expect the differences between viewer types to disappear in the *patches* condition but remain present (although potentially reduced) in the *strips* condition. Finally, when comparing the colorimetric values of the colours matched by participants and displayed on the ambiguous Dress picture, we could test which viewer types determined colours with the colour picker that were the closest to the displayed colours on the ambiguous Dress picture. In other words, we identified which viewer types overestimated or underestimated any of the perceptual attributes of colours as compared to the colorimetric signal of the ambiguous Dress picture. Based on the colour measurements of the ambiguous Dress image (Melgosa et al., 2015), we could expect that the colour matches will be the closest of B&Br viewers while the colour matches of two more extreme perceptions (B&B and W&G) will deviate from the displayed colours.

Study One: Demographic and other variables predicting the Dress perception

Participants

In the classroom, we tested a convenience sample of 240 undergraduate psychology students (52 males). They had a mean age of 21.91 years (*SD* = 4.61, range = 18-54 years). Three participants self-reported being colour blind, so they were excluded from the analyses.

Materials and Procedure

In a large lecture theatre (up to 500 places), students attended their weekly cognitive psychology lecture. Right at the start, just four days after the ambiguous Dress picture appeared on the Internet, they were invited to voluntarily take part in a survey on the Dress illusion. On two large projection screens (next to each other), we showed the ambiguous Dress picture. The ambiguous Dress picture was not calibrated to the screen because a) all participants were tested at the same time looking at the same monitors, and b) there was no clear way to calibrate the presentation of the ambiguous Dress image due to the lack of established perceptually relevant colorimetric values of the Dress image. We distributed a short questionnaire asking 1) the colour(s) of the Dress; 2) whether they have seen the Dress before (if *yes* they were labelled non-naïve), 3) whether the colours have changed since previous viewing (if *yes* they were labelled unstable); 4) where the light source seems to come from; 5) what type of light there seems to be (natural or artificial); 6) whether they had more or fewer hours of sleep than usual (how many) the night before; 7) whether they had consumed more or less coffee/black tea than usual on the day of testing; 8) what is their eye colour; 9) whether they are wearing glasses/contact lenses; and 10) demographic questions: age, gender, ethnical background. Participants took around 10 minutes to complete the questionnaire while looking at the ambiguous Dress image, upon which they were thanked and debriefed. We presented them the results of the survey about 4 weeks later.

Design and analysis

We analysed the data according to the different viewer types (B&B, W&G, B&Br, and Other). We used a chi-square test to compare the distribution of people in each viewer type group, and for different categories: 1) naïve vs. non-naïve participants, 2) stable vs. unstable perception. Then, we created a logistic regression model with several categorical and linear variables as predictors and viewer type (B&B or W&G) as an outcome variable. In this model, only the number of B&B viewers was compared to the number of W&G viewers to avoid biases due to low numbers of responses in the other categories. These were the predictor variables: 1) gender (male, female), 2) ethnicity (Caucasian, Asian, African, Latin American, or mixed), 3) type of light (natural, artificial, both), 4) light source in the image (behind, side, other), 5) sleep deprivation (linear: the number of hours slept the night before which were over or under the usual number), 6) caffeine consumption (more than usual, as usual, less than usual), 7) eye colour (blue, green, brown, mixed), 8) corrected vision (glasses or lenses vs. no correction), 9) age (linear variable). Data can be publicly accessed following this link: https://forsbase.unil.ch/project/study-public-overview/15066/0/

Results

The majority of participants saw the ambiguous Dress picture in B&B (47 %) or W&G (38%), and a few participants reported other colour combinations, namely B&Br and other (see Table 1, column *Number of participants*). Thus, the distribution of participants across all different viewer types varied significantly, $\chi^2(3) = 121.84$, $p < .001$, $V = .414$. When comparing B&B and W&G viewers only, the number of participants in the B&B and W&G groups did not differ, $\chi^2(1) = 2.40$, $p = .121$, $V = .109$.

[Insert Table One around here]

Most participants had seen the ambiguous Dress picture already (89% of non-naïve viewers, Table 1, column *Seen previously*). The number of non-naïve viewers did not differ per viewer type; $\chi^2(3) = 3.51$, $p = .319$, $V = .122$. Around one third of non-naïve viewers reported that the colours they saw during the experiment were different from the colours they had seen initially (Table 1, column *Change colour*). Around half of the unstable perceivers belonging to B&B, B&Br or Other viewer types had experienced a change in the perception of the ambiguous Dress colours, while only 16% of W&G viewers had experienced such change, and this difference was significant; $\chi^2(3) = 22.83$, $p < .001$, $V = .333$ (Table 1). By self-report (Table 1, column *Previous colour*), the majority of the unstable viewers had previously seen the ambiguous Dress picture as W&G but it changed to B&B or B&Br before or during the current testing session. Consequently, the change between W&G to B&B or B&Br was more common than from B&B or B&Br to W&G; $\chi^2(1) = 15.78$, $p < .001$, $V = .478$ (comparing the change from W&G vs. B&B and B&Br). The logistic regression with all the demographic predictors was not significant overall ($\chi^2(17) = 14.20$, $p = .653$) and none of the predictors were significant on their own (see Table 2).

[Insert Table Two around here]

Study Two: Context effects on the Dress colour reproduction

Participants

We tested 57 participants (10 males) with a mean age of 21.30 years (*SD* = 4.43, range 17-42 years). We performed a sample size power analysis (Mayr, Buchner, Erdfelder, & Faul, 2007) for a 2 x 3 x 3 mixed measures ANOVA (for more information, see *Data and Analysis* section). This analysis suggested that at an alpha level of 0.050 and beta level of 0.950, and assuming a correlation between repeated measures of 0.5 and epsilon of 1, the total sample size of 54 is sufficient to detect a medium effect size of 0.25. None of the participants was colour blind as confirmed using the Ishihara's Colour Blindness Test (Ishihara, 1993). Some of the participants received course credit for participation while others were remunerated in gift vouchers. Participants were free to choose a preferred form of gratification. All participants provided written informed consent prior to experimentation.

Materials

To test effect of decontextualization, we presented three types of stimuli taken from the Dress: (a) small *patches* cut out of different parts of the ambiguous Dress picture, evenly distributed (Figure 1, left), (b) vertical *strips* cut out of the ambiguous Dress picture (Figure 1, middle), and (c) the *full* ambiguous Dress picture (Figure 1, right). They varied from the least to the most recognisable, and for this reason were always presented in the same order: patches, strips, and the full ambiguous Dress picture. Also, surrounding context information was eliminated in the *patches* and *strips* condition but preserved in the *full* ambiguous Dress picture condition. Contrast information was reduced in the *patches* condition but preserved in the *strips* and the *full* ambiguous Dress picture conditions. The exact locations from which the *patches* and the *strips* were cut out are presented in Figure S1.

The least recognizable type of stimulus was the *patch*. Ten small patches were selected from the ambiguous Dress picture at various locations to correspond to white/blue and gold/black regions of the ambiguous Dress picture (see Figure 1, left, and Figure S1). The selected regions were similar to those investigated by Melgosa and colleagues (2015). The patches were displayed in the centre of the screen, one at a time. Four of these patches were cut from the lighter part of the ambiguous Dress picture (white or blue, depending on perception) – ”Light”, and six of these patches were cut from the darker part of the ambiguous Dress picture (gold or black) – “Dark”. We used six additional patches of comparable size taken from the pictures of two salamanders as control (see Figure 1 left and Figure 2). We chose salamanders instead of homogeneous single colour patches because these salamander patches were perceptually complex and acted as lure patches. We decided to use such "lure" patches to make the goal of the study (testing the ambiguous Dress picture) less obvious at this initial stage. All patches (test and control) were treated such that they encompassed the space of 2 x 2 cm (14,000 pixels) and a visual angle of 1.64° (see Table S1 in supplementary material).

The second type of stimulus, which we presented after the patches, was the *strip*. Two strips were vertically cut out from two ambiguous Dress locations (see Figure 1 middle and Figure S1), potentially recognizable as belonging to the ambiguous Dress picture by non-naïve viewers (similar stimuli used in Drissi Daoudi et al., 2017). The strips were not stretched. Their size was 19.1 x 1.3 cm, and they were presented in the centre of the screen. The vertical viewing angle was 15.6° and the horizontal viewing angle was 0.01°. The third type of stimulus, presented after the strips, was the *full* ambiguous Dress picture (see Figure 1, right). It was not manipulated in any way and presented exactly as it circulated the Internet. The picture size was 19.1 x 12.6 cm, the vertical viewing angle was 15.6° and the horizontal viewing angle was 10.2°. After the three experimental conditions, we further presented a picture of the same dress in unambiguous lightening conditions as control ("the real dress", see Figure 2). All the stimuli appeared on a neutral grey background in the centre of the screen. Participants were seated in a dark room, lit by a computer monitor only.

Colour picker

The colour picker provides a structured representation of colour patches showing eight variations (lighter, darker, more or less chromatic, more yellow, more blue, more red and more green) of the centrally presented colour patch shown on white background on the computer screen (Jonauskaite et al., 2016). It starts with the presentation of nine (red, orange, yellow, yellow-green, green, green-blue, blue, purple and grey) square colour patches on a white background (14.5 x 13.0 cm). In the current study, the eye-screen distance was kept constant at 70 cm. Thus, the colour picker extended to a vertical visual angle of 11.8° and a horizontal visual angle of 10.6°. After making an initial choice, participants had to narrow down their colour selection by clicking on a patch that most closely resembles the colour of the patch they were trying to match. The colour selection process as such is sequential so that with each selection the target (central) colour varies along various colour dimensions to a lesser degree. Once the variations reach a threshold, the central colour is singled-out as the final selection. It is then displayed in the centre of the screen on a white background; its size is 4.7 x 4.0 cm, making a vertical visual angle of 3.8° and a horizontal visual angle of 3.4°. The colour picker records the colour in RGB values. The key feature of this colour picker tool is that it allows a user-friendly, intuitive, and fast selection of any colour that the computer screen can produce.

Apparatus

The task was performed on three different monitors with identical specifications (Colour Edge CG243W 24.1" Widescreen LCD display). The white point of monitor one was (0.326, 0.345, 107.95); monitor two (0.326, 0.347, 102.64); and monitor three (0.326, 0.345, 98.96) in CIE xyY colour space. Similarly, the empirical primaries of monitor one were Red (R) = (0.642, 0.333, 23.9), Green (G) = (0.305, 0.581, 78.60), and Blue (B) = (0.140, 0.051, 5.45), monitor two – R = (0.641, 0.332, 22.1), G = (0.304, 0.584, 75.5), and B = (0.140, 0.049, 5.04), and monitor three – R = (0.641, 0.331, 21.9), G = (0.304, 0.583, 72.1), and B = (0.140, 0.050, 4.96). The viewing distance was approximately 70 cm in all cases.

Conversion of colour parameters

The colour selections were recorded with the colour picker tool as device-dependent RGB values. We converted the RGB values into CIE Lab and then CIE LCh values, which are device-independent, and thus more realistically describe actually perceived colours. This kind of conversion cannot be achieved purely arithmetically because the relationship between the device emitted luminance and the perceiver observed lightness is not linear. This non-linear relationship can be described by the gamma curve (Robson, 1999). In order to calculate the gamma curve, we used a Konica Minolta chromameter to measure Yxy values of the emitted colour from red, green and blue guns at different voltages for each of our three monitors and convert them into CIE LCh values. When performing the conversions, we took into account the monitor settings of the monitor that each participant performed the experiment on.

[Insert Figure One around here]

Procedure

The main task of the experiment was to reproduce the colours of each type of stimulus using the computerised colour picker program. Participants were not aware that the experiment was designed to test perception of the ambiguous Dress picture. The only information they had was that the experiment tested "colour perception". To keep the participants naïve as long as possible, we presented the conditions regarding contextualisation of the ambiguous Dress picture in this order: patches, strips and the full ambiguous Dress picture. The 16 patches were individually shown in the same order with dark, light and control patches inter-mixed (see the order in Figure 1, left). Participants were asked to use the colour picker (displayed on the right side of the screen next to the stimuli) and select the predominant colour of the stimuli displayed on the left side of the screen. Reference white was always available, which was considered to be the adapting monitor white-point. The presentation of the left strip, the right strip and the full ambiguous Dress picture followed the patches. Participants used the colour picker to first match the colours of the left and right strips cut from the ambiguous Dress picture (Figure 1, middle) and then of the full ambiguous Dress picture (Figure 1, right).

Afterwards, participants completed a short demographics questionnaire and were asked what colour(s) they saw on the ambiguous Dress picture, whether they had seen the picture before, whether its colour changed from previous viewing (specify), and what colour(s) they saw on the real dress. Based on the answer to the first question, participants were assigned into four self-reported viewer types: B&B, W&G, B&Br, or other. The experiment took around 50 minutes. Afterwards, participants received a voucher (10 CHF value) or two experimental participation points. Finally, they were thanked and fully debriefed. All participants were recruited from the same first year psychology student pool. They were free to choose their preferred method of remuneration. Around two thirds of the participants chose experimental participation points as remuneration.

Design and analysis

We had three independent variables (IVs) in this dataset. The first IV, between-subjects, was self-reported VIEWER TYPE with three levels: B&B, W&G, and B&Br. The second IV, within-subjects, was the PATCH COLOUR with two levels: dark (i.e. black or gold) and light (i.e. blue or white). The third IV, within-subjects, was CONTEXT with three levels: squares (i.e. out of context), strips (i.e. partially contextualized), and full Dress (full context of the ambiguous Dress picture). The colour selections for patches and strips were averaged across the different selections (i.e. six dark patch selections, four light patch selections, two dark strip and two light strip selections). We excluded two participants because of missing data. We further excluded three participants whose self-reported perception of the ambiguous Dress picture could not be categorised into one of the three viewer types – B&B, W&G or B&Br. Thus, all analyses were performed on 52 participants (9 males).

We broke down colour selections into three colour parameters making three dependent variables (DVs): CIE LCh hue (range 0°-360°), CIE LCh chroma (1-141) and CIE LCh lightness (1-100). Hue was a circular variable while lightness and chroma were linear variables. Differences in hue were analysed using one criterion analysis of variance (ANOVA) for circular data (Agostinelli & Lund, 2017). This method assumes that the samples are drawn from the *von Mises* distribution and tests whether all groups (here B&B, B&Br, and W&G) have the same mean direction (null hypothesis). We could implement circular statistics, because the hue data was unimodally distributed. We compiled six ANOVA models for circular data, Bonferroni corrected (i.e., *p* values were multiplied by the number of tests – i.e., six), to compare hue matches between the viewer types for dark and light patches, dark and light strips, and dark and light parts of the full ambiguous Dress image. Additionally, to test how colour categories match the circular hue angles, we binned hues into nine perceptually relevant categories (Jonauskaite et al., 2016; Parraga & Akbarinia, 2016): red (346°-40°], orange (40°-72°], yellow (72°-105°], yellow-green (105°-130°], green (130°-166°], green-blue (166°-220°], blue (220°-275°], and purple (275°-346°]. All these categories had chroma values above 5, while the last category – achromatic – had chroma values below 5 of any hue angle. We compared hue categories matched to the dark parts of the Dress and the light parts of the Dress using the marginal model for correlated multinomial responses (Bergsma, Croon, & Hagenaars, 2009; Bergsma & Van der Ark, 2015).

Differences in chroma and lightness levels were analysed using respectively a 2 x 3 x 3 mixed ANOVA with PATCH COLOUR and CONTEXT as within-subjects measure and VIEWER TYPE as between-subject measure. To account for the notion that the Dress phenomenon is continuous (Gegenfurtner et al., 2015), whenever significant interactions included VIEWER TYPE, the interactions were broken down with planned linear polynomial contrasts by arranging the viewers as B&B – B&Br – W&G. Finally, we used one-sample t-tests to compare the colorimetric values of hue, chroma and lightness of the selected colours (colour picker) and what was displayed from the ambiguous Dress image. All analyses were performed with R (R Core Team, 2018) and SPSS (IBM Corp, 2013) statistical software programs. Data can be publicly accessed following this link: https://forsbase.unil.ch/project/study-public-overview/15066/0/.

Results

In analogy to study one, we show the distribution of viewer types, naïve participants and those having reported unstable perceptions of the ambiguous Dress picture (Table 3). Statistically, all three viewer types occurred at the same frequency, $\chi^2(2) = 3.50$, $p = .174$, $V = .259$. That is, participants were equally likely to perceive the ambiguous Dress picture colours as B&B, W&G, or B&Br. Other comparisons were not made due to an insufficient number of cases in each bin.

[Insert Table Three around here]

Colour selections as a function of hue, lightness, and chroma values

Figure 3 shows the colours that participants matched to the darker and the lighter parts of the ambiguous Dress picture, its patches and strips. Simply descriptive, colour matches to the ambiguous Dress image seem more heterogeneous than colour matches to control patches or the real dress image (Figure 2). For comparison with other research studies, we further represent colour selections in CIE Lab colour space (see Figure S2).

[Insert Figure Two around here]

[Insert Figure Three around here]

ANOVA for circular data on hue showed no difference between VIEWER TYPES for *patch* condition (dark: $F(2, 49) = 0.83$, $p = 1.000$, $\eta_p^2 = .031$; light: $F(2, 49) = 0.25$, $p = 1.000$, $\eta_p^2 = .010$), *strips* condition (dark: $F(2, 49) = 0.57$, $p = 1.000$, $\eta_p^2 = .023$; light; $F(2, 49) = 0.24$, $p = 1.000$, $\eta_p^2 = .009$), or the light parts of the ambiguous *Dress* image ($F(2, 49) = 2.53$, $p = .539$, $\eta_p^2 = .090$). The difference between VIEWER TYPES emerged for the dark parts of the ambiguous *Dress* image ($F(2, 49) = 9.51$, $p = .002$, $\eta_p^2 = .257$), whereby B&B viewers matched redder hues (hues closer to 0°) compared to colour matches by B&Br ($p = .004$) or W&G ($p = .009$) viewers. Colour matches were statistically indistinguishable between B&Br and W&G viewers ($p = 1.000$; see Figure 4).

[Insert Figure Four around here]

Additional analyses with the marginal model for correlated multinomial responses showed that hue categories differed between PATCH COLOURS (χ^2 (7) = 296.59, $p < .001$) and CONTEXT conditions (χ^2 (14) = 46.01, $p < .001$) but not VIEWER TYPES (χ^2 (14) = 20.63, $p = .111$). Standardised residuals indicated that the dark parts were matched to orange ($p < .001$) and yellow ($p < .001$) hues significantly more often than the light parts, while the light parts were matched to blue ($p < .001$) and purple ($p < .001$) hues significantly more often than the dark parts across all three context conditions of the ambiguous Dress picture (Figure S3). Also, orange hue was significantly more often used for PATCH colours in *patches* than for *strips* or *full* ambiguous Dress picture colours ($p < .001$) while achromatic colours were significantly more often used for the *full* ambiguous Dress picture colours than for *patch* or *strip* colours.

The 2x2x3 ANOVA on lightness levels showed a main effect of VIEWER TYPE ($F(2, 49) = 16.73$, $p < .001$, $\eta_p^2 = .406$). Polynomial linear contrast indicated that B&B viewers' matched colours were the darkest while W&G viewers' matched colours were the lightest ($p < .001$). Importantly, there was a significant three-way interaction between VIEWER TYPE, CONTEXT and PATCH COLOUR pointing to the importance of context in which the ambiguous Dress was originally embedded; $F(4, 98) = 292.95$, $p < .001$, $\eta_p^2 = .165$ (see Figure 5, panel A). We compared the differences in lightness of the matched colours between B&B, B&Br, and W&G viewers separately for each context condition (i.e., *patch*, *strip*, and the ambiguous *Dress* image) using linear polynomial contrasts. There were no differences between VIEWER TYPES for *patch* condition, whether matching dark ($p = .922$) or light ($p = .940$) parts of the patches cut out of the ambiguous Dress picture. There were, however, differences between VIEWER TYPES for *strip* (dark: $p = .028$; light: $p = .021$) and the ambiguous *Dress* image (dark: $p < .001$; light: $p < .001$) conditions. In both *strip* and the *Dress* conditions, B&B viewers matched the darkest colours and W&G viewers matched the lightest colours while colour matches of B&Br viewers fell in between the two (see Figure 5, panel A).

[Insert Figure Five around here]

The 2x2x3 ANOVA on chroma levels did not show a main effect of VIEWER TYPE ($F(2, 49) = 1.99$, $p = .148$, $\eta_p^2 = .075$). However, as for lightness, there was a significant three-way interaction between VIEWER TYPE, CONTEXT and PATCH COLOUR; $F(4, 98) = 1305.61$, $p < .001$, $\eta_p^2 = .408$ (see Figure 5, panel B). Similar to results obtained for lightness, there were no differences between VIEWER TYPES for *patch* condition when matching dark ($p = .401$) and light ($p = .977$) parts of the patches cut out of the ambiguous Dress picture. In the *strip* condition, a linear contrast was significant between VIEWER TYPES for light ($p = .007$) but not dark ($p = .134$) parts of the strips cut out of the ambiguous Dress picture. B&B viewers matched the most chromatic light colours and W&G viewers matched the least chromatic light colours, while colour matches of B&Br viewers fell in between. In the ambiguous *Dress* condition, a linear contrast was significant between VIEWER TYPES for dark (p < .001) and light (p < .001) parts of the ambiguous Dress picture. B&B viewers matched the least chromatic colours for the dark parts and the most chromatic colours for the light parts, W&G viewers matched the most chromatic colours for the dark parts and the least chromatic colours for the light parts, while colour matches of B&Br viewers fell between matches of B&B and W&G viewers (see Figure 5, panel B).

Deviation of selected colours from presented (reference) colours

We used the Konica Minolta CS-100A chroma meter to measure the colorimetric signal of the displayed colours on the ambiguous Dress picture. We averaged across six points of the dark parts of the ambiguous Dress picture and six points of the light parts of the ambiguous Dress picture. After having done this separately on the three monitors, we averaged the CIE LCh values (obtained from xyY values) of the three monitors and established the reference colour for the dark parts of the ambiguous Dress picture and the reference colour for the light parts of the ambiguous Dress picture (see Table 4 column *Reference value*). For averaging hue values, we implemented circular statistics (Agostinelli & Lund, 2017). We compared lightness, chroma, and hue values of the matched colours with the reference colours, using one-sample t-tests for lightness and chroma, and one-sample ANOVA for circular data for hue. The comparisons were Bonferroni corrected, for lightness, chroma, and hue separately. This comparison gave us an indication of the extent of over- or underestimation of colour values by the viewers.

The majority of the colours matched by the viewers to the colours displayed on the ambiguous Dress picture deviated from the reference colours (Table 4). In general, B&B viewers matched lightness, chroma and hue the closest to the reference colorimetric values, except from chroma of the light parts of the ambiguous Dress picture ("blue / white"), which was slightly overestimated. The other two viewer types (i.e., W&G and B&Br) largely overestimated lightness of the light and the dark parts of the ambiguous Dress picture, and overestimated chroma of the dark parts. B&Br viewers, but not W&G viewers also overestimated chroma of the light parts of the ambiguous Dress picture. Finally, B&Br and W&G viewers matched hue of the dark parts of the ambiguous Dress picture as more yellow – their matches were shifted clockwise from the reference values. The observations are in line with the above reported ANOVA results. These results highlight the extent of the Dress illusion, as viewers overestimated colour parameters by 30% - 410% when compared to the displayed colorimetric values.

[Insert Table Four around here]

Discussion

The Dress picture went viral in early 2015 with people dividing into two perceptual camps – Blue and Black (B&B) and White and Gold (W&G) viewers. Subsequently, the scientific and popular media tried to explain this new visual illusion (Brainard & Hurlbert, 2015). We performed two studies right after the appearance of the ambiguous Dress picture online. Here, we investigated what variables can predict the colours that people see on the ambiguous Dress picture and how colour perception of different viewer types changes with increase of contextual information of the ambiguous Dress picture. In the first study, we investigated the proportion of different viewer types when seeing the same ambiguous Dress picture at the same time in a classroom setting and whether inter-individual variables could explain the differences in the perception of the ambiguous Dress picture. In the subsequent laboratory study, participants used a computer-based colour picker program to match perceived colours for light and dark parts of the ambiguous Dress picture, in that order, for patches, cut out of the ambiguous Dress picture, strips also cut out of the ambiguous Dress picture, and the whole ambiguous Dress picture. Here, we could test 1) whether perceptual attributes of colour (hue, chroma, and lightness) differed between viewer types; 2) whether the illusion persisted when the ambiguous Dress picture was decontextualized; and 3) which viewer type matched colours the closest to the displayed colours on the ambiguous Dress picture.

Results from the classroom study yielded three self-reported viewer types: the expected B&B and W&G viewers, but also the previously mentioned group of B&Br viewers. The frequency of particular viewer types varies between studies (Chetverikov & Ivanchei, 2016; González Martín-Moro et al., 2018; Karlsson & Allwood, 2016; Wallisch, 2017). Using an unconstrained colour term choice methodology in the current study, we report an approximately even split between B&B and W&G viewers (similar to Aston & Hurlbert, 2017; Chetverikov & Ivanchei, 2016; Hesslinger & Carbon, 2016; Karlsson & Allwood, 2016; Schlaffke et al., 2015; Vemuri et al., 2016; Winkler et al., 2015). We further confirm that several individuals reported seeing the ambiguous Dress picture as B&Br (Aston & Hurlbert, 2017; Lafer-Sousa et al., 2015; Mahroo et al., 2017; Wallisch, 2017; Witzel et al., 2017). While being conjectural, a bimodal distribution of Dress viewers might have arisen due to using forced-choices when testing participants' colour perception (i.e., asking them to choose between B&B and W&G) (see also Aston & Hurlbert, 2017; Lafer-Sousa et al., 2015; Wallisch, 2017; Witzel et al., 2017). Thus, our results support previous notions of a perceptual continuum (e.g., Gegenfurtner et al., 2015) instead of a bimodal distribution of B&B and W&G viewers (e.g., Chetverikov & Ivanchei, 2016).

B&B and B&Br viewers in the classroom study were more likely than W&G viewers to have experienced a change in the perception of the ambiguous Dress colours (see also Lafer-Sousa et al., 2015). During the classroom study as compared to prior viewing(s), we found that B&B and B&Br viewers reported a change in perception, i.e. not seeing the ambiguous Dress picture as W&G anymore, but as B&B or B&Br. This observation could explain why the initial Internet survey with 3 million participants (Holderness, 2015) reported a larger number of participants seeing the ambiguous Dress picture as W&G while later studies reported a more even split between B&B and W&G viewers (e.g., Karlsson & Allwood, 2016). Some initial W&G viewers might have become B&B or B&Br viewers after repeated exposure to this image.

In the laboratory study, one of the questions we wanted to know was whether perceptual attributes of colour (hue, chroma, and lightness) differed between viewer types. We answer yes, at least partially. Our data supports the notion of a continuum of Dress viewer types: B&B viewers reproduced darker ambiguous Dress picture colours than B&Br viewers, which reproduced darker ambiguous Dress picture colours than W&G viewers (see also Aston & Hurlbert, 2017; Chetverikov & Ivanchei, 2016; Gegenfurtner et al., 2015; Lafer-Sousa et al., 2015; Toscani et al., 2017; Witzel et al., 2017). When matching colours to dark (i.e., black/gold) and light (i.e., blue/white) parts of the ambiguous Dress image, B&B viewers reproduced the dark ones as more chromatic and light ones as less chromatic when compared to B&Br and then to W&G viewers. While the differences between lightness and chroma were rather large, we found fewer differences in reproduced hue.

For hue, the only difference between the viewer types emerged for the reproduced hue of the dark parts of the ambiguous Dress image. B&B viewers matched hues that were closer to a hue angle of 0°, i.e. redder, when compared to B&Br or W&G viewers. All viewers together, almost always selected the dark parts of the ambiguous Dress picture as having a yellow or an orange hue, and the light parts of the ambiguous Dress picture as having a blue or a purple hue. While hue differences were reported for reproduced Dress colours using various colour models (Aston & Hurlbert, 2017; Chetverikov & Ivanchei, 2016; Lafer-Sousa et al., 2015; Witzel et al., 2017), the current study shows that differences in hue perceptions are less detectable and obvious regarding the subjective report than in chroma and lightness.

Chroma and lightness differences between the viewer types can be easily compared with their subjective perceptions. Viewers who reported the lighter parts of the ambiguous Dress picture as being blue (i.e., B&B and B&Br viewers) perceptually matched darker colours and so accentuated the blue/purple hue. W&G viewers, who reported the lighter parts of the ambiguous Dress picture as being white, perceptually matched blue/purple hues as well but chose a very light version of them. This choice explains why the very light blue was named as white. Viewers who reported the darker parts of the ambiguous Dress picture as being gold or brown (i.e., B&Br and W&G viewers) perceptually matched lighter colours and so accentuated the yellow/orange hue. B&B viewers matched much darker and redder hues to the same parts of the ambiguous Dress picture and called them black. The redder hues might potentially be an artefact of choosing a very dark colour. Due to a cylindrical representation of the LCh colour space, colours of low lightness and chroma have poorly defined hue. A perfect black may by default be represented by the hue angle of 0°. However, this does not explain why B&B viewers matched a wide range of reddish hues, ranging from almost purplish (anti-clockwise from 0°) to red-orange (clockwise from 0°). In any case, the matched colours were very dark and perceptually appeared as almost black.

In the laboratory study, we also wanted to know whether the Dress illusion persisted when the ambiguous Dress picture was decontextualized. We again answer yes, at least partially. The differences in matched colours were most apparent for the contextualized ambiguous Dress picture (i.e., the original stimulus), somewhat less apparent for the strips and not apparent for the patches cut out of the ambiguous Dress picture. We observed a linear arrangement in the matched colours from B&B to B&Br to W&G viewers when the ambiguous Dress picture was presented as a strip as well as the whole ambiguous Dress picture. Hence, results indicate that differences between perceptions of the ambiguous Dress picture colours (i.e., viewer types) already appear in minimal context conditions. In other words, a reduced section of the ambiguous Dress picture is enough for the illusion to emerge. Emergence (although weaker) of the Dress illusion in the strip condition (the background was occluded) demonstrated that the surrounding context is not the essential driving force for the Dress illusion to occur (Chetverikov & Ivanchei, 2016; Drissi Daoudi et al., 2017; Wallisch, 2017; Witzel et al., 2017). A priori, our study was not designed to explain how context affects colour perception of the ambiguous Dress image. To this goal, different hypotheses have been proposed to explain the Dress illusion (e.g., Dixon & Shapiro, 2017; Hesslinger & Carbon, 2016; Witzel et al., 2017). Nevertheless, our results would invite for further investigation of contrast information (i.e., contrast between light and dark parts of the ambiguous Dress picture) as a potential explanatory factor for the Dress illusion. Such future studies should be designed to address the mechanisms of the Dress illusion and why individual differences in the ambiguous Dress perception persist in scenes hardly recognisable as the ambiguous Dress image (as shown here and in Hesslinger & Carbon, 2016). Potentially, the texture structure rather than the illuminated naturalistic scene is crucial in eliciting perceptual differences that disappear for uniform patches of similar chromaticities.

In the laboratory study, we finally wanted to know which viewer type matched colours the closest to the actual colours displayed on the monitor. Although we had expected B&Br viewers' colour matches to be the closest to the displayed colours, since their matches always fall between the other two viewer types (Aston & Hurlbert, 2017), we observed that B&B viewers' colour matches were the closest to the displayed colours. We compared lightness, chroma, and hue values of the colours that participants matched with the colours of the ambiguous Dress picture that were displayed on the monitors. Comparing these, we had an indication of how much subjective perception of the colours of the ambiguous Dress picture deviated from the displayed colorimetric values. We could determine which viewer types over- or underestimated the colorimetric parameters of the ambiguous Dress picture. The colorimetric values of the B&B viewers' reproductions were the closest to the displayed values. Both W&G and B&Br viewers considerably overestimated lightness and chroma of the ambiguous Dress picture in the matched colours. They also matched colours shifted towards the yellow hue (i.e., away from 0°) compared to the displayed colours. Considering that the ambiguous Dress picture displays bluish and brownish colours (Melgosa et al., 2015), one could expect that these displayed colours (in terms of their lightness and chroma) are most similar to what B&Br perceivers reproduce. Nonetheless, our current data indicates that B&B perceivers most accurately match the displayed colours as compared to both W&G and B&Br perceivers who over-estimate colorimetric parameters. The question opens as to why the majority of people (i.e., those who perceive W&G and B&Br) cognitively resolve the ambiguous stimulus so that it leads to an illusionary percept? The extent of the Dress illusion is large; it affects the majority of people, and deserves further attention.

To summarize, we performed two studies on the ambiguous Dress picture to contribute to on-going research efforts aimed at understanding this new visual illusion. In our first classroom study, participants' self-report resulted in the clustering of individuals into B&B, B&Br, or W&G viewers. These groups did not differ according to subjectively perceived light source or inter-individual factors. The laboratory study indicated that contextualization is key for the Dress illusion to occur and contrast or texture information might be the driving force. Moreover, results on lightness and chroma highlighted previous notions that the illusion occurs at a continuum from W&G, to B&Br, to B&B viewers, with the latter being most closely in their colour matching to what has been actually displayed on the monitor. Our results contribute to an increasing knowledge base on the Dress illusion, but remains insufficient explaining why so many individuals (W&G, B&Br) over-estimate colour parameters of the ambiguous Dress picture and only few individuals (B&B) perceive colours close to what has actually been displayed. Even knowing that contextualization, contrast, and illumination are important for the illusion to occur, these factors are not yet able to explain why individuals differ so strongly in their subjective perception. While currently light source (Chetverikov & Ivanchei, 2016) and one-shot learning (Drissi Daoudi et al., 2017) are some suggestions, we are certain additional suggestions will be communicated in the years to come.

Compliance with Ethical Standards

Funding: The current study did not receive any specific funding.

Conflict of interest: None declared.

Ethical approval: All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. No specific ethical clearance was received for this study, as it was not required by the Canton of Vaud in Switzerland law.

Informed consent: Informed consent was obtained from all individual participants.

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Tables

Viewer type	Number of participants (% from total)	Seen previously – non-naïve (% from the number in the category)	Changed colour – unstable (% from those who saw previously)	Colour seen previously (% of unstable viewers)			
				B&B	W&G	B&Br	Other
B&B: Blue & Black	112 (47.3%)	99 (88.4%)	44 (44.4%)	2 (4.5 %)	40 (90.9 %)	2 (4.5 %)	0 (0 %)
W&G: White & Gold	90 (38.0%)	82 (91.1%)	13 (15.9%)	7 (53.8 %)	1 (7.7 %)	3 (23.1 %)	2 (15.4 %)
B&Br: Blue & Brown	16 (6.8%)	12 (75.0%)	6 (50%)	1 (16.7 %)	5 (83.3 %)	0 (0 %)	0 (0 %)
Other or missing data	19 (8.0%)	17 (89.5%)	9 (52.9%)	1 (11.1 %)	5 (55.5 %)	2 (22.2 %)	1 (11.1 %)
Total number	237 (100%)	210 (88.6%)	72 (34.3%)	11 (15.3%)	51 (70.8%)	7 (9.7%)	3 (4.2%)

Table 1. The descriptive data of the participants in relation to viewer type in Study One.

Predictors of the viewer type (B&B or W&G)	χ^2 statistic
Gender	1.51
Age	0.54
Ethnicity	3.68
Eye colour	2.31
Corrected vision	0.01
Sleep deprivation	2.29
Caffeine	0.48
Type of light	0.19
Light source	1.87

Table 2. Predictors of the ambiguous Dress viewer type (B&B or W&G) in the Study One included in the logistic regression. None of the predictors were significant.

Viewer type	Number of participants (% from total)	Seen previously (% from the number in the category)	Changed colour (% from those who saw previously)
Blue & Black	12 (21.82%)	12 (100%)	3 (25.00%)
White & Gold	17 (30.91%)	15 (88.24%)	5 (33.33%)
Blue & Brown	23 (41.82%)	17 (73.91%)	5 (29.41%)
Other	3 (5.45%)	2 (66.66%)	2 (100%)
Total number	55 (100%)	47 (85.45%)	16 (34.04%)

Table 3. The descriptive data of the participants in relation to viewer type in Study Two.

Colour parameter	Dress part	Viewer type	Mean	SD	Reference value	Statistic (significance)
Lightness	Light	B&B	59.46	7.59	53.6	2.68
		B&Br	73.83	11.59	53.6	8.37***
		W&G	85.91	11.98	53.6	11.12***
	Dark	B&B	25.47	16.10	37.8	-2.65
		B&Br	60.40	11.24	37.8	11.77***
		W&G	59.52	9.20	37.8	7.97***
Chroma	Light	B&B	34.58	15.21	17.9	3.80*
		B&Br	23.20	6.96	17.9	3.67**
		W&G	12.10	9.34	17.9	-2.56
	Dark	B&B	13.04	15.68	9.2	.85
		B&Br	38.32	17.97	9.2	7.77***
		W&G	46.83	10.16	9.2	15.28***
Hue	Light	B&B	270.20	0.18	279.1	0.67
		B&Br	269.34	0.13	279.1	1.53
		W&G	256.68	0.54	279.1	0.54
	Dark	B&B	16.50	1.33	36.7	0.11
		B&Br	79.40	0.12	36.7	34.20***
		W&G	81.10	0.08	36.7	80.11***

Table 4. One-sample t-tests to compare the deviation of the selected colours from the colours displayed by the monitor (i.e., reference value). * $p < 0.050$, ** $p < 0.010$, *** $p < 0.001$ (Bonferroni correction applied separately for lightness, chroma, and hue). For hue variable, circular statistics were implemented to calculate mean, standard deviation (SD) and deviation from displayed colour values.

Figures

Figure 1. **The ambiguous Dress picture related stimuli tested in Study Two**. Context conditions were always presented in the same order: patch (1-16), strip (17-18), and Dress (19). Left panel presents 16 patches cut out from the ambiguous Dress picture (D = dark part; L = light part) or control lure stimuli (C = control). Middle panel presents two strips cut out of the left side (17) and the right side (18) of the ambiguous Dress picture. The right panel present the full ambiguous Dress picture (19). In the strip and the Dress conditions (17-19), participants matched a predominant colour of dark and light parts (D&L).

Figure 2. Colour matches for control patches. Control selections are displayed to exemplify a small individual variation in colour selections of stimuli that are other than the ambiguous Dress picture. Control patches were cut out from the specified locations of the yellow-green salamander and the blue frog. The black-and-blue dress was presented as a whole. For all images, participants were instructed to match colours of the most predominant colour(s) of the image. Please note that the displayed colours are only approximate representations of the participant colour matches.

Figure 3: Colour matches of dark and light parts of the ambiguous Dress picture displayed by viewer types and context. Please note that the displayed colours are only approximate representations of the participant colour matches.

Figure 4: Circular histogram of hue matches. Hues were matched to the dark (top) and the light (bottom) parts of the ambiguous Dress picture, displayed by context condition (patch, strip, and the ambiguous Dress image). The histogram bins are 15° each (radial light grey separators). Each bin is divided into three parts to encompass selections of each viewer type. Viewer types are colour coded (B&B = darkest, B&Br = medium, W&G = lightest). The y axis was square root transformed to make the area of each bar correspond to the number of hue choices.

Figure 5. Mean lightness (A) and chroma (B) levels of the matched colours. Light and dark colours were matched by Blue and Black (B&B), Blue and Brown (B&Br) and White and Gold (W&G) viewers in the three context conditions, displayed in fixed order: patch, strip, or the ambiguous Dress image.

Supplementary material

Patch number	Size in cm	Patch colour	Average *RGB* value			Average *CIELCh* value		
			R	*G*	*B*	*L*	*C*	*H*
1.	1.1 x 1.7	Dark	66	55	32	23.54	14.09	71.80
2.	1.3 x 1.7	Light	94	104	136	44.92	21.93	280.37
3.	0.7 x 1.4	Dark	59	49	39	20.56	8.48	51.24
4.	0.8 x 1.7	Light	90	102	150	44.70	30.63	283.13
5.	0.8 x 1.7	Dark	62	54	47	23.22	4.87	35.32
6.	0.8 x 1.3	Dark	101	87	52	38.80	19.57	278.62
7.	1.1 x 1.1	Light	132	142	174	60.23	19.57	278.62
8.	0.7 x 1.3	Dark	75	63	50	27.57	8.86	50.04
9.	0.7 x 1.3	Light	85	92	129	40.51	24.96	285.11
10.	0.7 x 1.3	Dark	55	45	63	19.42	17.11	306.59

Table S1. Sizes and colour parameters of the original patches (before stretching).

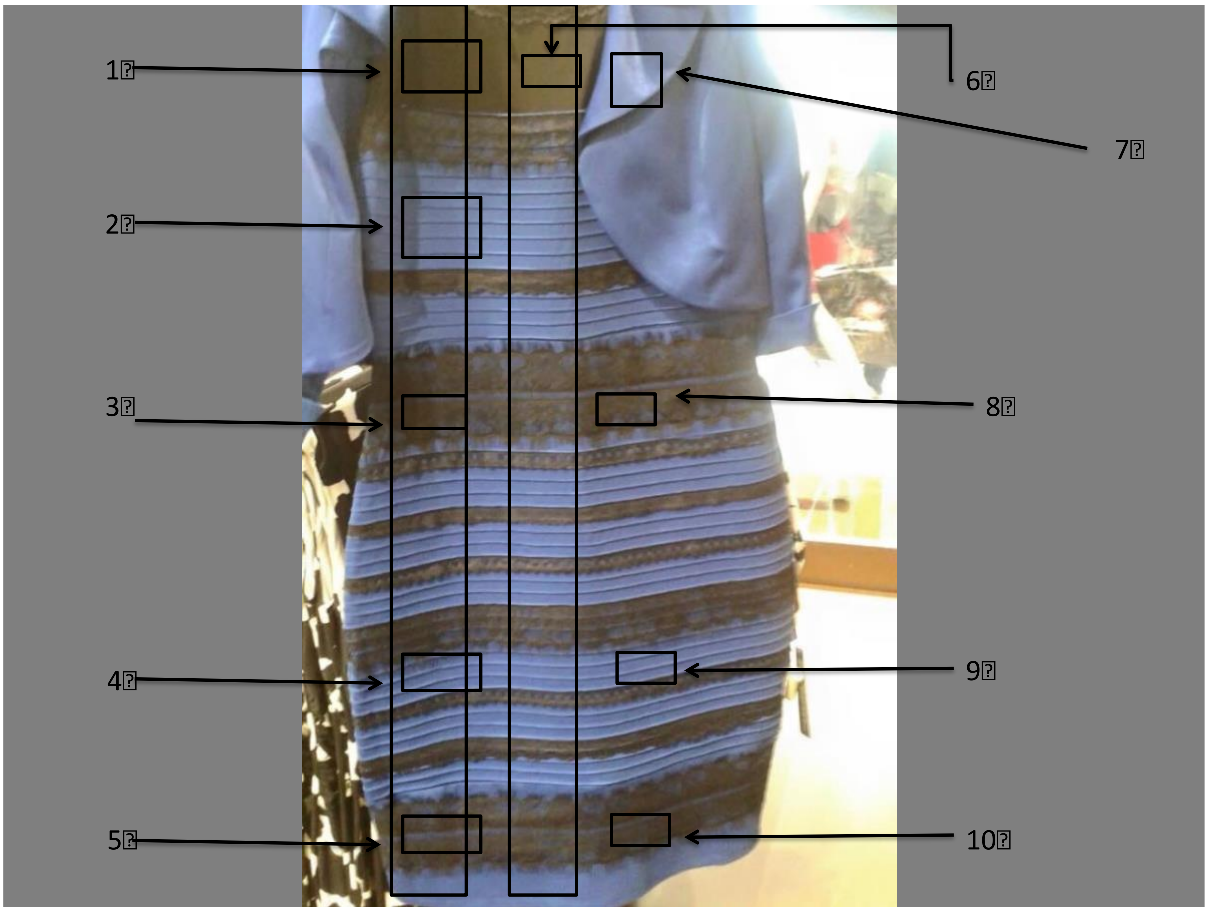

Figure S1. The picture of the ambiguous Dress picture. We indicate the exact locations from which the patches and strips were cut out for the different presentations (Study Two). These locations should be used in reference with Figure 1 detailing the order of the experiment.

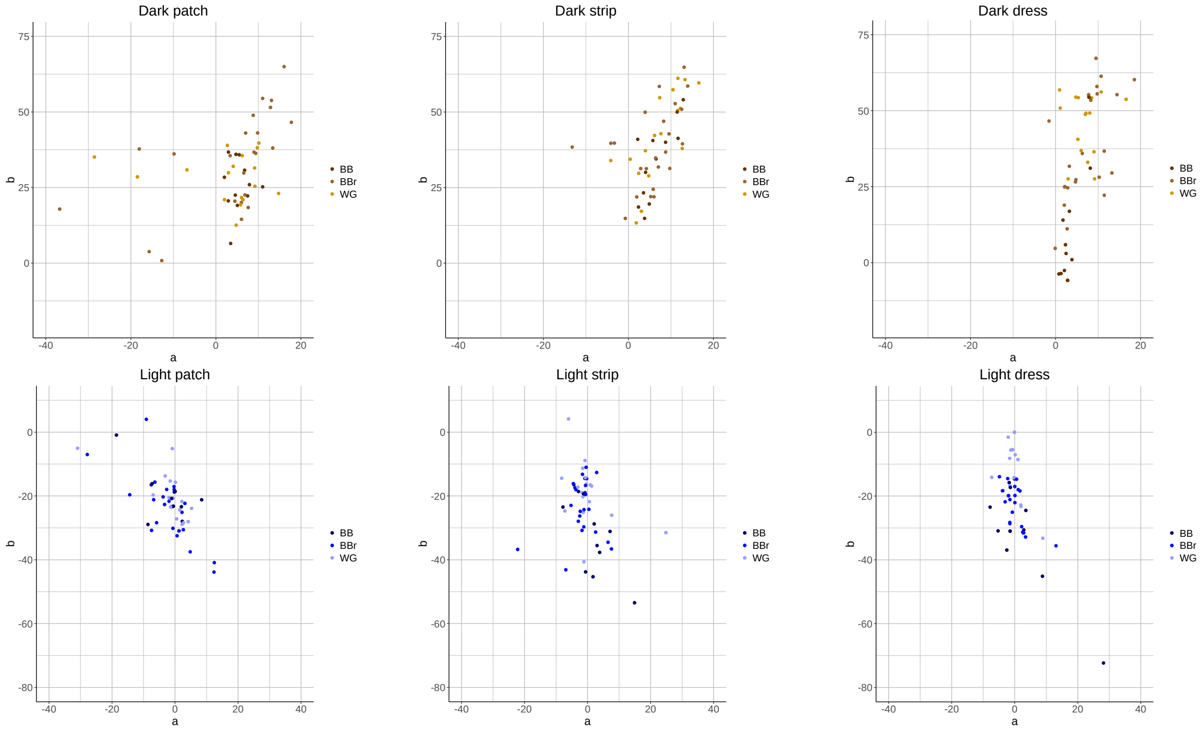

Figure S2. Participant colour selections for light and dark parts of the three context conditions (patch, strip, and the ambiguous Dress image) displayed on CIE Lab space.

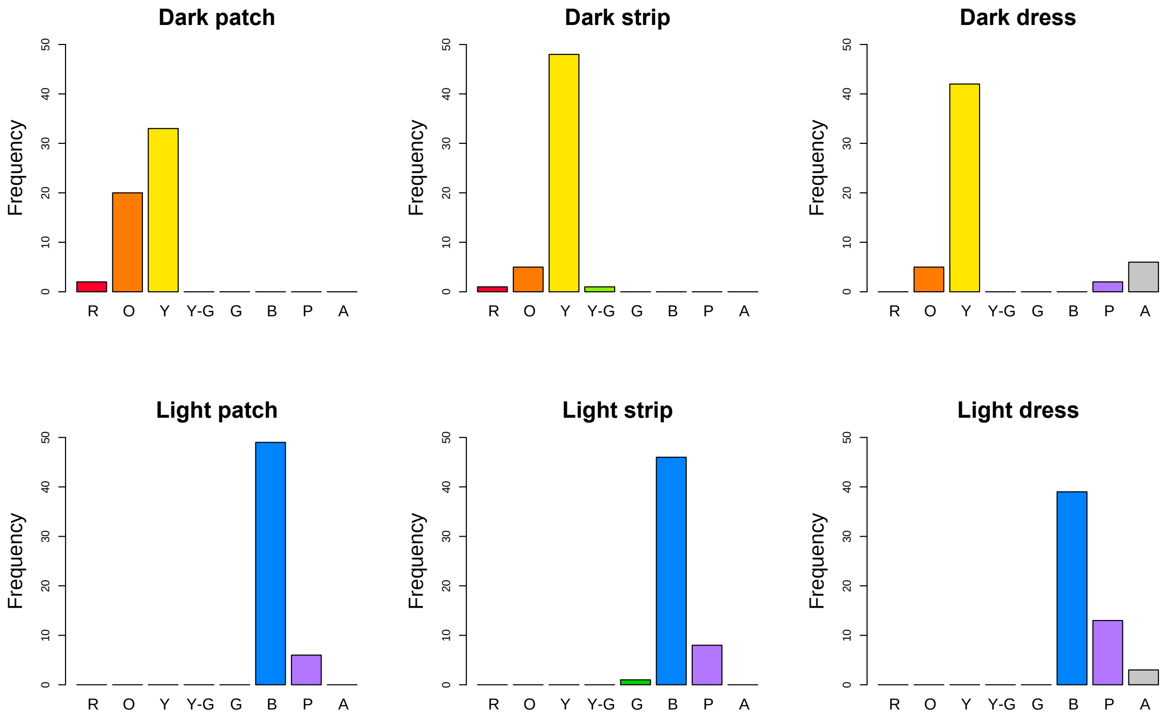

Figure S3. Hue distribution of the matched Dress colours. Colours were matched from the dark and the light parts of the Dress displayed by context (patch, stripe, Dress). R = red (346°-40], O = orange (40°-72°], Y = yellow (72°-105°], Y-G = yellow-green (105°-130°], G = green (130°-166°], B = blue (220°-275°], P = purple (275°-346°], and A = achromatic (chroma less than 5, any hue angle). Hue category green-blue (166°-220°] is missing from this graph because no one matched a colour from this hue range.