The role of saturation in colour naming and colour appearance

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Saturation is an integral part of colour perception. Yet, this aspect of colour vision has been widely neglected in research on colour naming and colour appearance. Fundamental questions about colour naming and colour appearance need to be reconsidered in the light of the important role of saturation. These questions concern the variation of measurements across studies, the relationship between category prototypes and unique hues, cross-cultural regularities in colour categorization, focal colours and the salience of category prototypes, and the role of unique hues in colour appearance.

Keywords: colour categorization, colour naming, colour vision, chroma, saturation

1. Introduction

What is saturation? Colloquially speaking, saturation may be understood as the "amount" of a given hue. For example, consider you have a colour of a particular red hue; the redness of that colour may be rather pale and "washed out" (desatu- rated) or "strong" and "vivid" (saturated).

Scientifically, saturation is defined as the attribute of a colour, according to which the colour appears to be more or less chromatic. A more precise distinction may be made between colourfulness, chroma and saturation (Fairchild 2013) depending on whether chroma is considered relative to its lightness (saturation) or absolute brightness (colourfulness). However, this difference is of minor impor- tance in the present context, and for the sake of simplicity saturation will be used to refer here to both chroma and saturation.

Technically, saturation corresponds to the difference of a colour from neutral (or achromatic) greyscale colours. In a perceptual colour space it may be quantified as the distance of a colour from the lightness (achromatic) axis. In other words, saturation corresponds to the radius of a colour coordinate in the respective space. In contrast, hue corresponds to the angle (or azimuth).

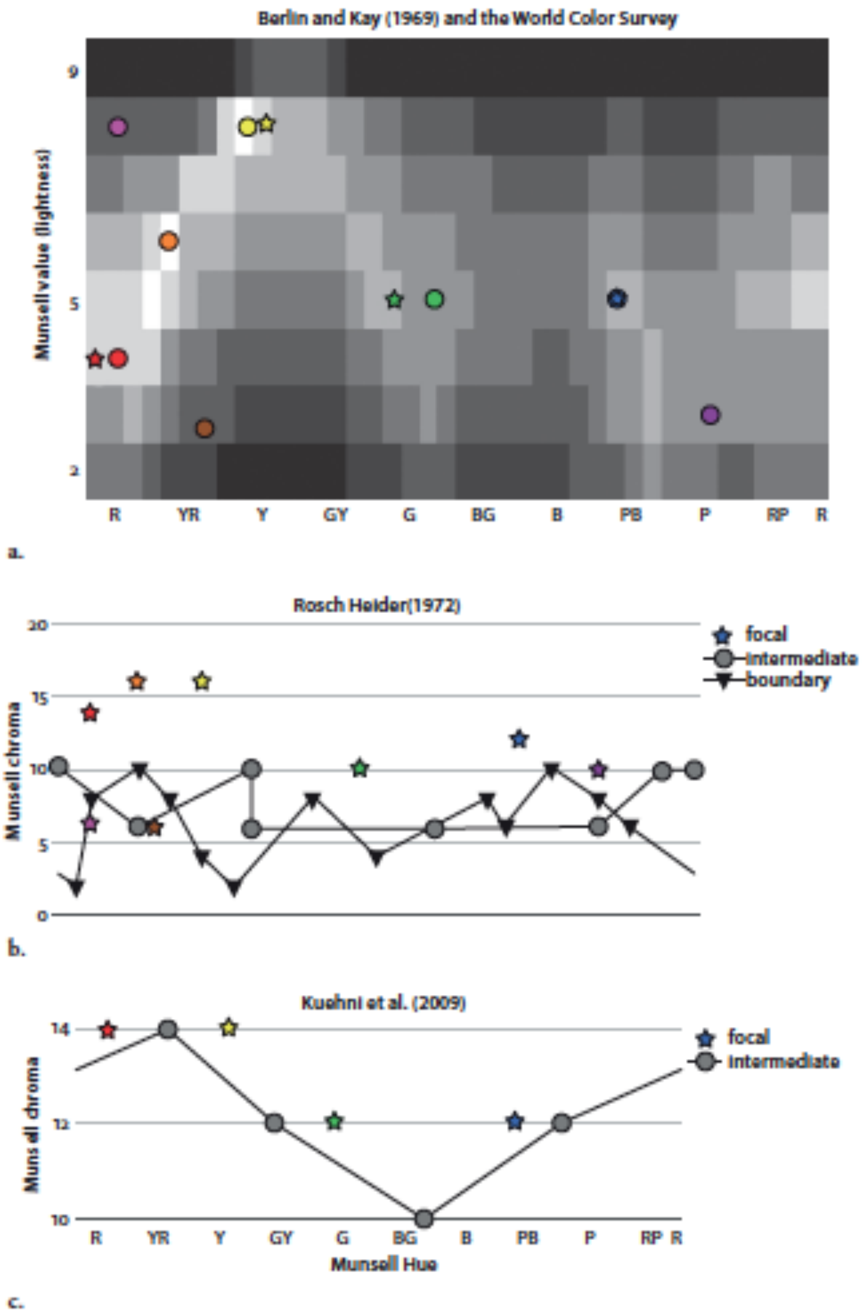
In *colour naming*, colours are described through colour terms in a language. These colour terms group the large range of perceivable colours into a few *basic colour categories*, such as orange, red, or brown (Berlin and Kay 1969; for a review see Witzel 2018; Witzel and Gegenfurtner 2018a).

Colour appearance refers to how a colour is subjectively perceived (or experienced) by an observer, and is typically assessed by reference to unique hues. A unique hue is an elementary colour that appears to be pure and unmixed (e.g. Kuehni 2014; Valberg 2001). Red, yellow, green and blue are considered to be the four unique hues. All other colours are perceived as a mixture of these unique hues. The colour appearance of a purple shade, for example, consists of a mixture of unique red and unique blue. The perceived saturation and lightness of colours may be achieved by adding black and white to combinations of unique hues.

Research on colour appearance and colour naming has neglected the role of saturation. In studies on unique hues, stimulus colours have been specified as spectral lights (Abramov and Gordon 1994; 2005; Fuld, Werner, and Wooten 1983; Hurvich and Jameson 1955; Quinn, Rosano, and Wooten 1988; Sternheim and Boynton 1966), in cone-opponent spaces (De Valois, De Valois, Switkes, and Mahon 1997; Hansen and Gegenfurtner 2006), or in device-dependent spaces (Buck and DeLawyer 2014; Foote and Buck 2014; Stoughton and Conway 2008). None of these approaches controls the perceived saturation, not even coarsely (e.g. Kulp and Fuld 1995; Mollon 2009; Ovenston 1998; for spectral colours, device- dependent spaces, and cone-opponent space respectively).

Figure 1. Maximally saturated Munsell chips in studies on colour naming and unique hues. Graphics illustrate the distribution of Munsell Chroma across stimuli used in classical colour-naming studies (a, b) and in a recent unique hue study (c). Panel (a) represents the complete set of maximally saturated Munsell chips as used in seminal cross-cultural comparisons of colour naming. Panel (b) represents the Munsell chips used in the cross-cultural study of Rosch Heider (1972), and panel (c) the Munsell chips in the study by Kuehni, Shamey, Mathews, and Keene (2010). In all panels, the *x*-axis corre-

sponds to Munsell Hue. In panel (a), lightness (Munsell Value) is shown along the *y*-axis, and lightness of the greyscale rectangles represents Munsell Chroma (light areas indicate high Munsell Chroma). In panels (b) and (c), the *y*-axis represents Munsell Chroma, and variation of lightness is not shown. Coloured stars correspond to category prototypes (in (a) and (b)) or unique hues (in (c)) respectively. Grey circles refer to intermediate colours (in (b) and (c)). Black triangles represent colours at category boundaries (in (b)). In panel (a), the stars correspond to the cross-cultural prototypes found in the World Color Survey (Regier et al. 2005). Coloured disks are the prototypes found for English speakers by Berlin and Kay (1969). These prototypes are the same as those used by Rosch Heider (1972) and, hence, correspond to the stars in panel (b). Note that category prototypes and unique hues (coloured symbols) are mostly located in regions of high Munsell Chrpoma.



Most importantly, seminal studies on colour naming (e.g. Berlin and Kay 1969; Brown and Lenneberg 1954; Lindsey, Brown, Brainard, and Apicella 2015; Regier, Kay, and Cook 2005; Rosch Heider 1972) and unique hues (for a review see Kuehni 2014) have used a set of maximally saturated Munsell chips. The Munsell system is a collection of standard colour chips, the Munsell chips, which are ar- ranged by lightness, hue and saturation in a way that is meant to reflect subjective appearance (see e.g. Fairchild 2013). In the Munsell system, these dimensions are called *Munsell Value*, *Munsell Hue* and *Munsell Chroma*, and they organize the colour chips into an irregular, asymmetric volume, which is known as the *Munsell Solid*. This shows "bumps" (local maxima of saturation) in different directions be- cause the maximal saturation (Munsell Chroma) varies across lightness and hue.

As illustrated in Figure 1a, the saturation bumps of the Munsell Solid coincide with the prototypical colours of some of the English basic colour terms, in particular, red, orange, yellow, green and blue (Collier 1973; Jameson and D'Andrade 1997; Regier, Kay, and Khetarpal 2007). As a result, when studies investigated colour naming and colour appearance with maximally saturated Munsell chips, the saturation of their stimuli was higher for the prototypes of those English basic colour terms than for non-prototypical colours (see examples in Figure 1).

In sum, different studies have used different approaches to sample colours, but in all of these approaches perceived saturation varied across hues. Nevertheless, barely any study has considered whether and how observations about colour categories and unique hues might be affected by the variation of saturation in the stimulus samples. This chapter discusses four lines of argument that support the important role of saturation in colour naming and colour appearance.

2. Measuring categories and unique hues

Although there is a conceptual difference between unique hues and colour catego- ries, there is a potential link between unique hues and the hues that correspond to the prototypes of the red, yellow, green and blue categories (*typical hues*). A cor- respondence between unique hues and typical red, yellow, green and blue would establish a direct relationship between colour appearance and colour naming (Kay and McDaniel 1978; Kuehni 2005; Regier et al. 2005).

In recent studies (Witzel and Franklin 2014; Witzel and Gegenfurtner 2018b; Witzel, Maule, and Franklin, under revision) we extensively measured unique hues and typical red, yellow, green and blue, while roughly controlling saturation across hues through an equal radius in the CIELUV space. To measure unique hues, observers were asked to adjust the hue of a coloured disk so that it showed only one hue and not the slightest trace of any adjacent unique hue (e.g. the yellow that is neither red nor green). Category prototypes were measured by asking observers to adjust the hue that corresponds to the most typical example of a colour term (e.g. the most typical red). The resulting unique hues did not differ systemati- cally from the typical hues (Witzel and Franklin 2014; Witzel and Gegenfurtner 2018b; Witzel et al., under revision). However, other studies found that empirical measurements of unique hues do not always correspond to the typical hues of the red, yellow, green and blue categories. This is particularly true for typical and unique green (Kuehni 2001).

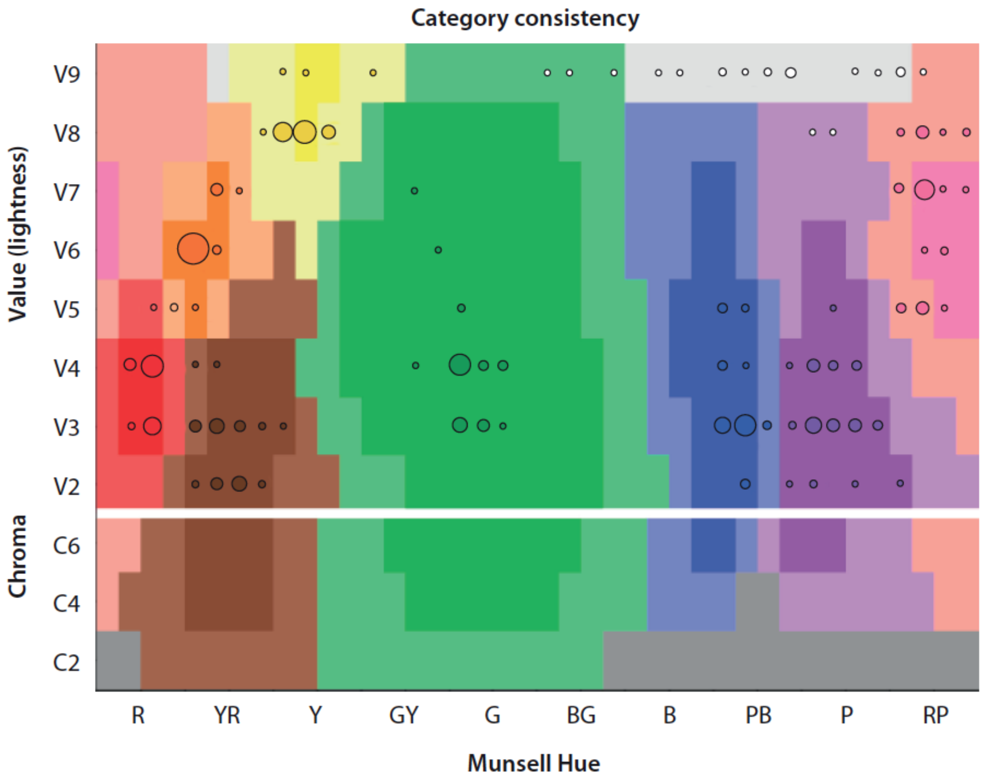
One possible reason for the discrepancy between measurements of typical and unique hues may be an effect of saturation. Conceptually, saturation plays a fun- damentally different role for unique hues than for category prototypes and colour categories. Colour categories and their prototypes depend on all three dimensions of hue, lightness, and saturation (cf. Figure 2a; see also e.g. Figure 8 in Olkkonen, Witzel, Hansen, and Gegenfurtner 2010; the Discussion in Witzel and Gegenfurtner 2013). In particular, saturation distinguishes chromatic (red, yellow etc.) from achromatic categories (black, grey and white). As a consequence, observers tend to choose the most saturated colours as prototypes of the chromatic categories (e.g. Experiment 1 in Rosch Heider 1972; Figure 8 in Olkkonen et al. 2010).

The relationship between saturation and color categorization is illustrated in Figure 2 with the data from Olkkonen et al. (2010) and two additional observers: category prototypes (depicted by circles) were chosen only from maximally satu- rated colours and never from desaturated colours (Figure 2a). Moreover, category consistency was correlated with Munsell Chroma ($r(438) = 0.35$, $p < 0.001$), as shown by the reanalysis of the data in Figure 2b. Category consistency describes how consistently a colour is named and categorized across repeated measurements and across observers. Hence, it reflects the strength of category membership of each colour.

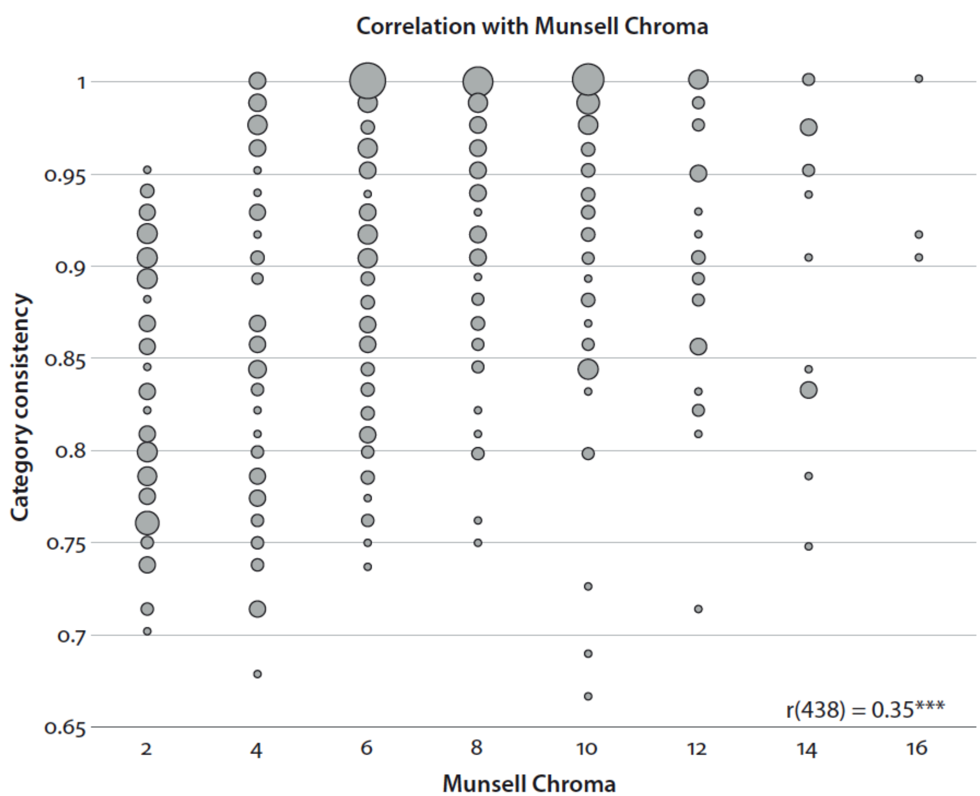
In contrast, unique hues are conceptually defined by their hue independent of saturation. For example, a greyish green may not be as typical as a saturated green, while both may be perceived as a unique green if they contain neither yellow nor blue (as illustrated in Figure 3). As a consequence, the variation in saturation may differentially affect the measurement of category prototypes and unique hues. In measurements of typical colours, observers may have to compromise between choosing the most typical hue and the most typical saturation. This is the case when saturation varies across hues in a way that dissociates typical hue and satura- tion. In contrast, measurements of unique hues might not be affected by varying saturation across hues. As a result, the variation of saturation across hues may produce a discrepancy between measurements of unique and typical hues that would not occur when saturation is controlled across hues, as was the case in Witzel and Franklin (2014).

At the same time, the fact that unique hues are conceptually defined by hue does not guarantee that unique hue measurements are unaffected by saturation. In contrast to the idea of unique hues, observers might take differences in saturation across hues into account, when judging the proportional amounts of two hues in hue cancellation or hue scaling. For example, they might consider a highly satu- rated red with a slight bluish tint to contain more red than a very greyish, desatu- rated unique red. This would explain why measurements of unique hues may vary considerably across studies with different setups and stimulus sets (Kuehni 2014).

Figure 2. Category membership for saturated and desaturated colours. Panel (a) illustrates category consistency across hue, saturation and lightness (for a more detailed representation see Figure 8 in Olkkonen et al. 2010). The horizontal axis represents Munsell Hue. The upper part of the vertical axis corresponds to eight levels of Munsell Value (lightness) at maximum saturation (cf. Figure 1a), and the lower part to the three lowest levels of Munsell Chroma at medium lightness (N5). The coloured disks cor- respond to prototype choices: the larger the disk, the more often the colour was chosen as a prototype. The coloured areas illustrate colour categories. The light areas indicate colours for which category consistency was below 90%. Reproduced from Witzel and Gegenfurtner (2018a) with permission of *Annual Review of Vision Science*. Panel (b) quantifies the relationship between Munsell Chroma and category consistency. The size of the disks corresponds to the frequency of a data point. The correlation is reported in the lower right corner. Note that desaturated colours are never chosen as prototypes (disks in panel (a)). Moreover, note that areas of low consistency are larger for desaturated colours (lower part of the diagram in panel (a)) than for maximally saturated colours (upper part). This is captured by the significant positive correlation between Munsell Chroma and category consistency (panel (b)).


Category consistency
Value (lightness)
V9
V8
V7
V6
V5
V4
V3
V2
Chroma
C6
C4
C2
R
YR
Y
GY
G
BG
B
PB
P
RP
Munsell Hue

a.


Correlation with Munsell Chroma
Category consistency
1
0.95
0.9
0.85
0.8
0.75
0.7
0.65
2
4
6
8
10
12
14
16
r(438) = 0.35***
Munsell Chroma

b.

In a recent study (Witzel and Hammermeister, under revision) we showed that observers chose different colours with different hues as category prototypes depending on how the stimulus sample varied in saturation. In addition, the variation of saturation also affected which hues observers identified as unique (for example when choosing the yellow that is neither red nor green). The effect of saturation tended to be lower for unique hue than for prototype choices, but was nevertheless highly significant. These results indicate that saturation influences the measurement of category prototypes and unique hues.

Taken together, the control of saturation is important for the theory and the measurement of category prototypes and unique hues. In particular, it is necessary for assessing the correspondence between category prototypes and unique hues and, hence, for understanding the relationship between colour appearance and colour naming.

Universality of colour categories

Seminal studies observed regularities in colour categorization across fundamentally different languages (Berlin and Kay 1969; Lindsey and Brown 2009; Lindsey et al. 2015; Regier et al. 2005; Rosch Heider 1972). In particular, the World Color Survey compared colour names in 110 non-industrialized societies. Despite differ- ences in colour names, Regier et al. (2005) observed that the choices of category prototypes across the non-industrialized languages clustered around the English prototypes for red, yellow, green and blue. Moreover, a recent study found that the distribution of colour categories both in non-industrialized Hadza observers from Tanzania and in Somali observers was highly similar to that of American observers (Lindsey et al. 2015).

All these studies used samples of maximally saturated Munsell chips. This set of Munsell chips may push observers to compromise between most typical hue and lightness, on the one hand, and high saturation, on the other (Witzel and Hammermeister, under revision). For example, observers might choose a very saturated green Munsell chip over a less saturated Munsell chip as the best example for green, even though the hue of the saturated chip might be less typical than the hue of a less saturated chip (as illustrated in Figure 3). In this case the difference in saturation produces a hue shift of the prototype choice away from the typical hue, i.e. the hue of the selected colour is biased due to the variation of saturation.

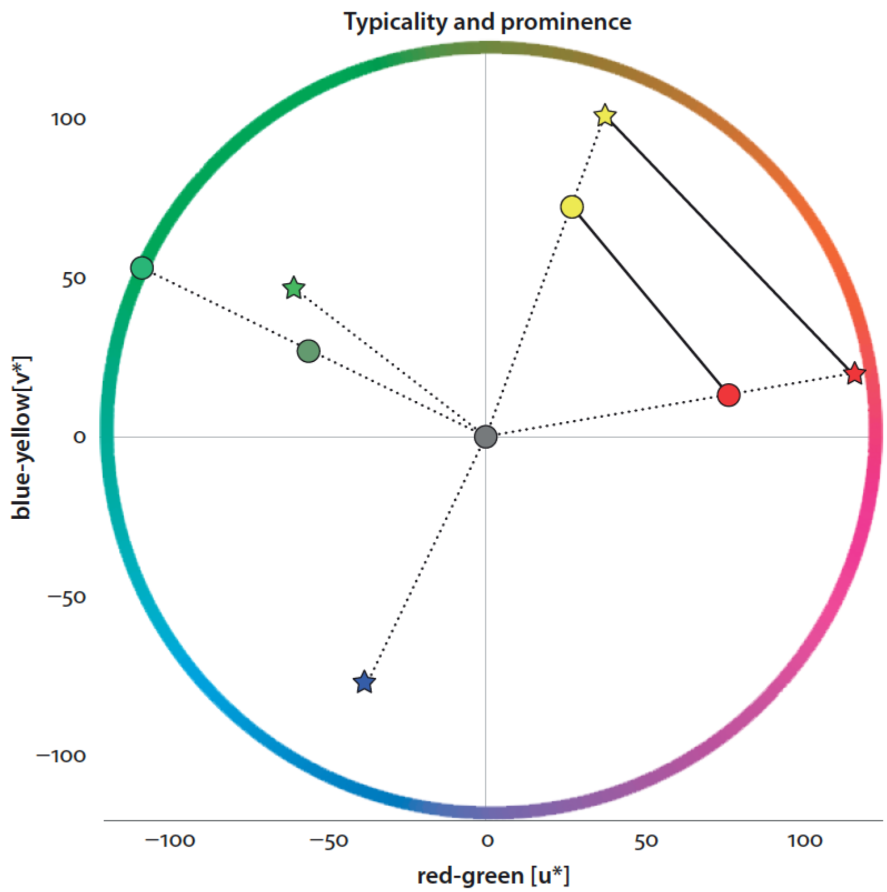


Figure 3. Typicality and perceptual prominence. The graph illustrates three theoretical arguments (see Sections 2–4). The *x*-axis is the red-green, the *y*-axis the blue-yellow dimension in CIELUV space. Saturation (CIELUV chroma) is the distance from the origin. Hues (azimuth) are illustrated by the bold coloured circle. Stars correspond to the Munsell chips identified as unique hues by Kuehni et al. (2010). Disks correspond to colours with a different hue (green) and/or a different saturation (red and yellow) than Kuehni et al.'s Munsell chips. The dotted line indicates hue direction of each colour. The green disk with lower saturation has the saturation of the green-blue intermediate hue in Kuehni et al. (2010). The green disk belonging to the circle indicates a highly saturated green colour that might be perceived as more typical than unique green (green star). The solid black lines serve to emphasize that the difference between two chosen colours increases with increasing saturation (i.e. distance from origin).

A tendency towards choosing more saturated colours as prototypes for chromatic categories implies that the Munsell chips with highest saturation might be the most likely choices of category prototypes – not because of their typical hue and lightness, but because of their high saturation. As a consequence, the variation of saturation across Munsell chips might produce a tendency to choose those Munsell chips as best exemplars (and category boundaries) across languages just because they have particularly high saturation (and low saturation respectively).

This idea is strongly supported by the correlation between the variation of saturation in the stimulus set and measures of prototype choices in the World Color Survey (see Figure 5 in Witzel, Cinotti, and O'Regan 2015). The variation of saturation across maximally saturated Munsell chips may also explain similarities in category membership (measured by naming consistencies) between non-indus- trialized languages and English. For example, category consistency in Hadza and Somali observers correlates with saturation of the maximally saturated Munsell chips (Lindsey, Brown, Brainard, and Apicella 2016; Witzel 2016). Consequently, the observed cross-cultural patterns in colour categorization might well be due to the unequal distribution of saturation in the stimulus samples (Witzel 2016).

4. Salience of "focal colours"

To explain the particular role of English prototypes in colour categorization it has been suggested that the prototypes of English colour categories are particularly "sa- lient" and "linguistically codable" (e.g. Brown and Lenneberg 1954; Rosch Heider 1972; Sturges and Whitfield 1997). English category prototypes were termed focal colours, under the assumption that they have a particular perceptual or cognitive property and correspond to the "foci" of universal colour categories, independent of language (Berlin and Kay 1969; Rosch Heider 1972).

Using the set of maximally saturated Munsell chips, a study provided evidence that those focal colours have particular perceptual characteristics (Regier et al. 2007). According to this study, colour categories of the 110 non-industrialized languages of the World Color Survey were distributed so that the Munsell chips within the respective categories tended to be more similar than those across categories. The authors argued that high similarity around the category centres showed that focal colours are perceptually salient (in a broad sense) and that categories developed around these perceptually salient colours. In addition, a recent study found that the difference between unique hues subjectively appears to be larger than the differences between intermediate hues (Kuehni, Shamey, Mathews, and Keene 2010). According to that observation unique hues are *perceptually prominent*.

Perceptual prominence and larger differences between categories than within categories may be a direct consequence of differences in saturation. Since more saturated colours are further away from the adapting white-point, differences between two hues increase with saturation. This is illustrated by the yellow and red disks in Figure 3. These disks correspond to colours that have the same hue as the unique red and yellow (yellow and red stars) in Kuehni et al.'s (2010) study, but have lower saturation. Since they are closer to the origin, they are also closer to each other. Hence, the fact that maximally saturated red, yellow, green and blue Munsell chips are more saturated than intermediate hues may explain why these colours are perceptually prominent (Kuehni et al. 2010), and why colours are less similar between categories than within categories (Regier et al. 2007).

Furthermore, saturation is strongly related to perceptual salience (Witzel and Franklin 2014; Witzel et al., under revision). Perceptual salience is determined by the contrast of a stimulus to its surround. For colours on a grey background, the saturation and lightness determine their chromatic contrast to the background and, hence, their salience.

Since the maximally saturated Munsell chips for typical red, yellow, green and blue have particularly high saturation, they are also particularly salient. High perceptual salience would explain why these colours play a particular role in colour naming and colour appearance. If these colours have comparatively high perceptual salience this would qualify them as "focal colours", around which colour categories and colour appearance are organized, independent from cultural and linguistic influences (Jameson and D'Andrade 1997; Regier et al. 2007).

However, the colour gamut of the Munsell chips is not necessarily representative of the visual gamut. Instead, the gamut of the Munsell chips may also be limited by the choice and combination of pigments used to produce Munsell chips (for a discussion see Munsell 1912). The upper boundary of perceivable saturation is determined by monochromatic lights that define the *visual gamut*,

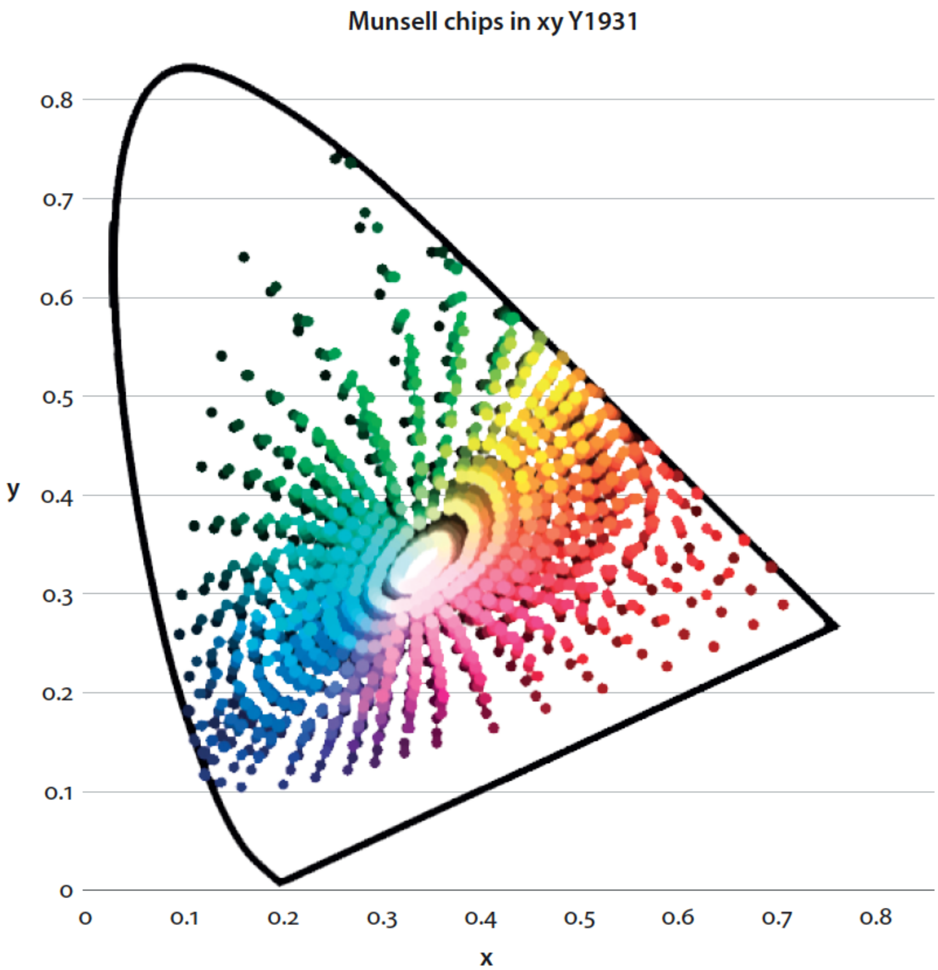


Figure 4. Munsell chips and visual gamut; *x*-axis and *y*-axis represent coordinates in the CIE1931 chromaticity diagram. The coloured dots show chromaticity coordinates of all Munsell chips under illuminant C. The black curve framing the dots corresponds to the visual gamut. Note that the Munsell chips do not cover the complete area of visible chromaticities, delimited by the visual gamut.

i.e. the limits of perceivable chromaticity in human colour vision. When represented in the chromaticity diagram (Figure 4), the gamut of Munsell chips does not follow the horseshoe shape of the visual gamut. In the chromaticity diagram, Munsell chips are close to the visual gamut for yellow, red, and blue colours, but not for purple, cyan and green colours. However, the chromaticity diagram in Figure 4 does not allow perceived saturation to be assessed.

For this reason, we measured discrimination thresholds for differences in saturation and estimated perceived saturation at the visual gamut (Witzel et al., under revision). Typical red, yellow, green and blue did not yield highest levels of perceived saturation compared to intermediate colours. These results did not so much depend on the particular estimation of the maximum saturation based on the visual gamut, but on the fact that the sensitivity to saturation (i.e. Weber frac- tion) is lower for some typical than for intermediate hues. We also compared the subjective appearance of saturation with saturation measured in terms of discrimi- nation thresholds (Witzel and Franklin 2014). In particular, we assessed whether typical hues appear more saturated than other hues, when saturation is kept equal in terms of cumulative discrimination thresholds; however, this was not the case.

In sum, existing evidence contradicts the idea that red, yellow, green and blue have a comparatively high perceptual salience and seems to be a consequence of how human observers perceive saturation. Instead, high saturation of category prototypes is a peculiarity of the maximally saturated Munsell chips.

Based on the analyses of maximally saturated Munsell chips, some studies have claimed that typical red, yellow, green and blue are more predictable (singu- lar) across illumination changes (Philipona and O'Regan 2006; Vazquez-Corral, O'Regan, Vanrell, and Finlayson 2012). However, these properties of maximally saturated red, yellow, green and blue Munsell chips may also be explained by the peculiarity of the stimulus sample (Witzel et al. 2015). In addition, recent studies undermined the idea that typical red, yellow, green and blue are perceived as more constant under illumination changes when saturation is controlled (Witzel, van Alphen, Godau, and O'Regan 2016; Weiss, Witzel, and Gegenfurtner 2017).

Taken together, important previous findings on the perceptual salience of typi- cal red, green, yellow and blue may be explained by a bias in stimulus sampling. Hence, it remains an open question whether red, yellow, green and blue really have particular perceptual properties that qualify them as focal colours.

5. The uniqueness of intermediate hues

Finally, unique hues (together with black and white) have been considered as pure elementary colours that can be mixed, in the perception of the observer, to produce the appearance of intermediate colours (e.g. Kuehni 2014; Valberg 2001). In this context, unique hues have been represented as part of a three-dimensional colour appearance space with axes that correspond to Hering's opponent colours (e.g. Figure 2 in Jameson 2010; Figure 2A in Valberg 2001; see also Fairchild 2013; Kuehni 2014; Wuerger and Xiao 2016). The idea that unique hues are arranged along opponent axes in colour appearance space has been used as the basis for the Natural Colour System (NCS) and as a benchmark to evaluate other colour ap- pearance models, such as the Munsell system, CIELUV, CIELAB and the CIECAM series (for an overview see Fairchild 2013).

In such a theoretical colour appearance space the extreme poles of the axes delimit the achievable perceived saturation (Figure 5). The appearance of any non- unique, intermediate colour is represented as a perceptual mixture of the unique hues, plus black and white. Perceptual mixture of hue corresponds to a circle in that space (Figure 5). The saturation of the hue can be reduced by adding the opponent hues. For example, some green and yellow may be added to a purple colour to reduce its saturation. In this kind of perceptual mixture, the saturation of an intermediate colour can never be higher than the saturation of the unique hues. However, our measurements of perceived saturation showed that there are blue-red colours with a perceived saturation higher than that of either blue or red (Witzel and Franklin, 2014; Witzel et al., under revision). These colours have levels of saturation that colours with other added hues cannot reach. In this sense, these intermediate colours have a “unique saturation”. According to the perceptual mixture of unique hues described above, the perceptual mixture of unique blue and unique red results in a hue that lies on the hue circle with the maximal saturation of the unique hues (Figure 5). The saturation of the resulting colour can be reduced by adding opponent colours, but it cannot be increased by adding unique hues, black and white. Hence, the perceptual mixture of unique hues, black and white cannot account for the appearance of all perceiv- able colours.

In addition, the findings presented in Section 2 suggest that unique hues can- not be determined independent from saturation. This observation undermines the idea that unique hues can be used to define perceived hue independent of saturation, and that they can be independent dimensions of colour appearance.

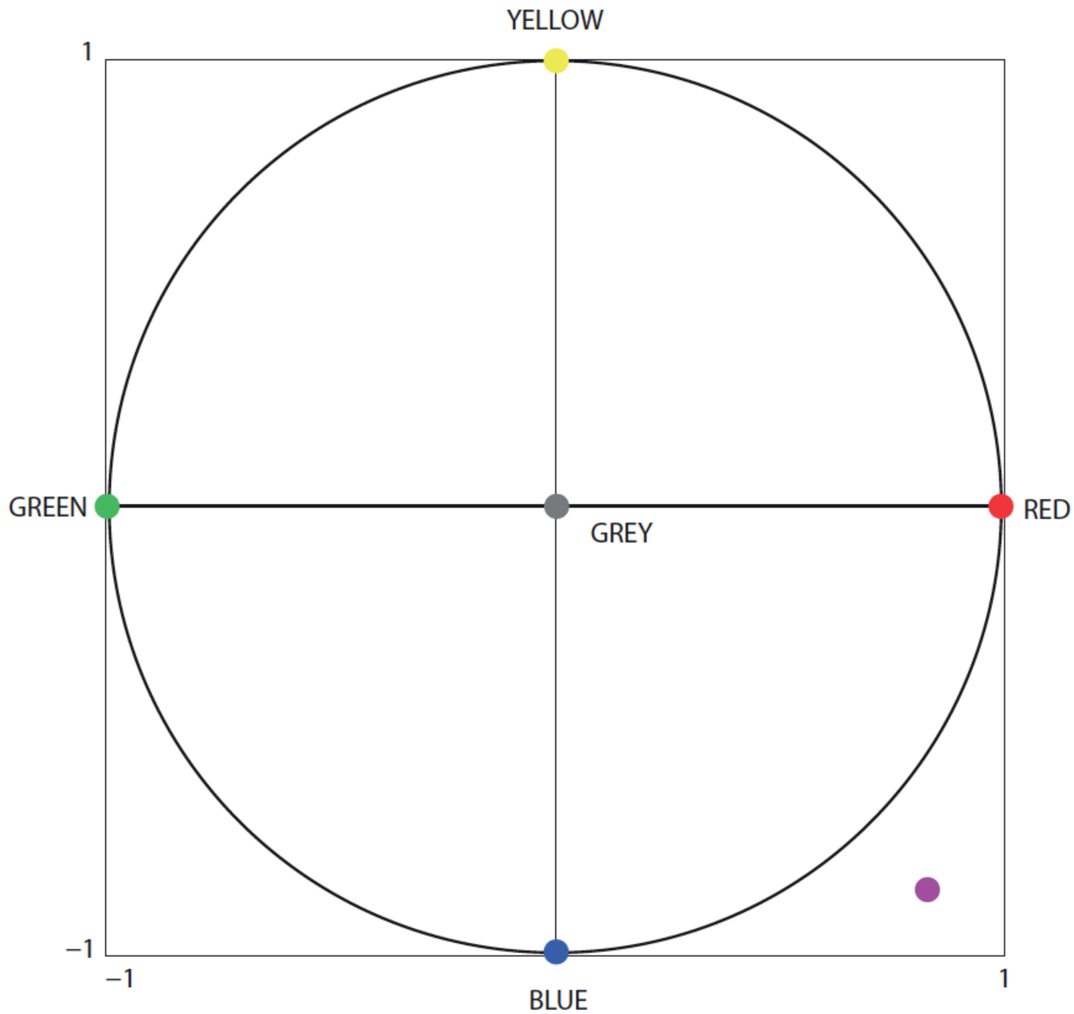


Figure 5. Theoretical colour appearance space based on unique hues. The poles of the axes (red, yellow, green and blue) correspond to the unique hues at maximal saturation (arbitrary unit of 1), the centre indicates achromatic grey, and the radius (i.e. the distance from achromatic grey) corresponds to perceived saturation. The black circle illustrates perceptual mixtures of unique red, yellow, green and blue at maximum saturation. This representation is adapted from similar representations in the literature (e.g. Figure 2 in Jameson 2010; Figure 2a in Valberg 2001). The purple disk illustrates a red-blue colour that is more saturated than the maximal saturation of red, yellow, green and blue and, hence, is located outside the black circle. Although this is a simplified representation to illustrate the theoretical argument, empirical measurements (Witzel et al., under revision) showed that the maximum saturation of some bluish red colours is higher than the maximum saturation of unique blue and red.

Taken together, these observations suggest that the concept of opponent unique hues (together with black and white) is not appropriate to fully describe and understand colour appearance. These findings raise the question of whether unique hues provide an adequate basis for theories and models of colour appearance (cf. Fairchild 2013; Jameson 2010; Valberg 2001; Wuerger and Xiao 2016). Attempts to account for the role of perceived saturation in colour appearance might offer an alternative approach to establish the fundamental dimensions of colour appearance models.

6. Conclusion

In sum, colour naming and unique hue measurements depend on chroma and saturation. Variation in saturation across stimuli may explain differences in measurements across studies and differences between measurements of unique hues and typical colours. Moreover, the coincidence of peaks in Munsell Chroma with typical and unique red, yellow, green and blue is a peculiarity of the Munsell system, rather than a characteristic of colour vision (Witzel and Franklin 2014; Witzel et al., under revision). This peculiarity of the Munsell system is strongly re- lated to cross-linguistic similarity of colour categorization and prototype choices, such as those found in the World Color Survey (Witzel 2016; Witzel et al. 2015; Witzel et al., under revision). Hence, observed cross-cultural patterns in colour naming might well be due to the unequal distribution of saturation in the stimulus samples, in particular when maximally saturated Munsell chips are used. These observations highlight the importance of controlling saturation in colour-naming research (Witzel 2018; Witzel & Gegenfurtner 2018b). With respect to unique hues, the present findings raise the question of whether unique hues can serve as genuine elementary colours for reconstructing colour appearance of all other perceivable colours, given that they cannot attain the degree of saturation of some intermediate (non-unique) hues.

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