Colour Naming – Linking Vision and Speech

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Abstract
Colour naming links vision and speech. In a cognitive model the colour in an external stimulus is encoded as a visual percept, which is matched against a store of colour percepts in long-term memory. The result is an index enabling a word or phrase to be retrieved from a colour lexicon. The colour name is a category label for a region of colour space, and has an inherent uncertainty because of differing perceptions of the locations of the centres of regions and of the boundaries dividing them. The dataset gathered from an online experiment supports a probabilistic colour naming algorithm.

What's in a Name?

"Tis but thy name that is my enemy;
Thou art thyself, though not a Montague...
What's in a name? That which we call a rose
By any other name would smell as sweet."

William Shakespeare (1595),
Romeo and Juliet (Act 2, Scene 2)

In her speech in the famous balcony scene, Juliet carefully separates the object of her affection from his name. Although Romeo is a member of the enemy Capulet clan, she understands that his name is only a label and that he would, she supposes, have the same personal qualities whatever he were called. She goes on to assert that the qualities of the rose (the referent) would persist, whatever its name (the reference). But, as with all metaphors, this argument is not entirely convincing because it overlooks other less desirable characteristics of the rose, such as its thorns and its wilting.

If she had not had other things on her mind, Juliet might have reflected upon metonymy. Literally meaning 'a change of name', metonymy is defined as "The substitution of a word denoting an attribute of a thing for the word denoting the thing itself".[1] Thus the word *rose* can be substituted for any of the attributes of the plant of that name, in particular the scent and the colour (Fig. 1).

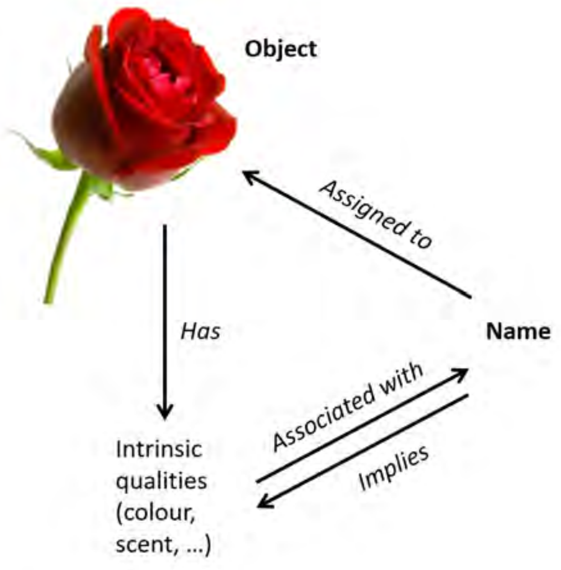

Figure 1. Rose as metonym

Casson observed that the metonym is based on contiguity relationships, whereas metaphor is based on similarity relationships.[2] The Old English word *rose*, derived from Latin *rosa*, had already taken on its metonymic sense by 1530, when English colour vocabulary had evolved from brightness concepts to predominantly hue concepts. This development coincided with the 'explosion of colour' that occurred in the late medieval period, particularly in the 14th Century Italian renaissance[3], precisely the period about which Shakespeare was writing. As an aside, perhaps Juliet was also acknowledging that her relationship with Romeo would have to be *sub rosa* (literally 'under the rose', hence in secret), from the rose that in ancient times was hung over the council table as a token of secrecy. One can encapsulate colour metonymy as "Entity stands for entity's colour." The entity names that became colour names were drawn from five object domains: plants, animals, minerals, foods, and artefacts. These semantic domains served as resources for the innovation of secondary colour terms, by providing familiar words that could be easily and widely understood throughout the cultural group.

Uncertainty in Colour Concept

The concept associated with a colour name is personal, something learned in childhood. It depends on individual learning experiences, from contact with parents, books, school and the world around.[4] Yet for communication within a community there has to be some shared implicit agreement on the meaning of each colour name. What is the probability that my mental prototype for a particular colour name is the same as yours? How can I know whether when I say *rose* or *róża* that you will envision the same colour? In practice, there is always a variance across the population. By way of demonstration, take a page of a colour atlas and ask a number of people to select the patch corresponding to a given colour name, for example pink in Fig. 2.

Figure 2. Which is the pinkest pink?

One of the reasons for uncertainty in colour vision arises from the genetic variation in spectral sensitivity of the retinal photoreceptors, leading to observer metamerism. Because no two people have exactly the same physiological responses to wavelengths across the visible spectrum, there can never be perfect agreement on the match between a metamer pair (two similar colours of different spectral composition). In fact there is no such person as the Standard Observer (CIE or otherwise), who represents a mean across the population of non-deficient observers; the standard deviation from the mean is represented by the Standard Deviate Observer.[5] There is an inherent uncertainty whenever a selection is to be made from a continuous gradation of colour (Fig. 3).

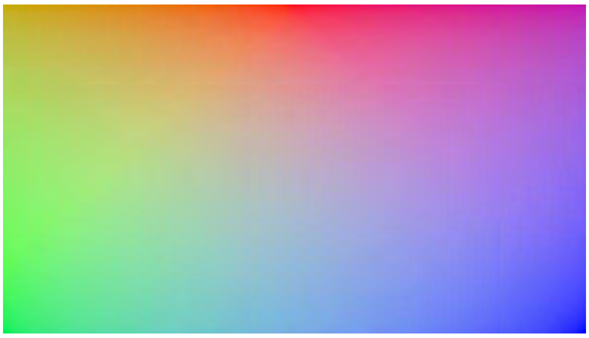

Figure 3. Where is grey? Where are boundary lines between colours?

Where is the grey point, i.e. the least chromatic point on the colour plane? A series of observers will identify different locations, clustered somewhere around the centre of the image, from which the centroid gives the best estimate. This technique is being used in an experiment to investigate the effect of ambient light on chromatic adaptation, employing a tablet computer with a touch screen.[6] Where are the boundaries between the colour regions, for example between blue and green? The problem is that, although there is clearly an overall gradient from one principal colour to another, the change in colour from one point to the next is imperceptible. This is an example of the Sorites Paradox, originally stated as “When taking grains of sand from a heap, at what point does it cease to be a heap?” The logical argument is that, on a continuous scale, if a value cannot be distinguished from its neighbour then both must belong to the same category and therefore by induction all points in the scale must belong to a single category. One way to resolve the paradox is to note that the sum of many small differences may become large enough to exceed a specified threshold. Therefore one might specify that the colour region consists of all points within, say, 10 ΔE^*_{ab} colour difference units from the ‘focal’ colour centre. An alternative is to look beyond perceptual scales at cognitive categories, based on language. Davidoff even speculates that “human language might have evolved to solve the otherwise intractable problem of producing categories that cannot be established by judgments of perceptual similarity”.[7]

Cognitive Model of Colour Naming

An analogous uncertainty occurs in the judgement of the accuracy of colours in the reproduction of images, for example in print or display media. According to Hunt, "the basis of judgement is usually a comparison between the colour perceptions aroused by the reproduction, and a mental recollection of the colour perceptions previously experienced when looking at similar objects".[8] The remembered colour may not be the actual colour of the original object or scene, but a modified or idealised version. Thus the grass may be remembered as greener and the sky bluer and the skin ruddier than they really were, and these memories influence the preferences for colours in the reproduction of photographs.[9] In the judgement of image quality, moreover, experimental subjects preferred images seen in isolation on a television screen with contrast and colour saturation enhanced by up to 10% over the original.[10]

Whereas approximately four million colours are discriminable by the human visual system,[11] in any language there are only a few thousand colour names (words and phrases). Therefore the mental process of converting a colour stimulus into a colour name involves a many-to-one mapping, with a thousand-fold reduction in the number of elements. The function of the brain in colour naming is shown schematically in Fig. 4 as a kind of cognitive architecture.[12] The eye and retinal apparatus generate a neural stimulus of the colour in a region of the visual field. This is conveyed via the optic nerve to the visual cortex where it is registered in area V4 as a colour percept (a facet of perception), in this case *red*. Long-term memory contains the stored percepts of many different colours, and these are retrieved and compared with the incoming percept by a parallel processing network to find the best match, resulting in an identification of the colour. The response depends on the task and may be non-verbal, for example pointing to a target or typing on a keyboard or (if driving a car) applying the brake. For a verbal response, the cognitive match acts as an index to a lexicon of colour names, eliciting an item for articulation as the word "red". The lexical retrieval and speaking processes increase the overall time period between the first view of the object and the spoken response.

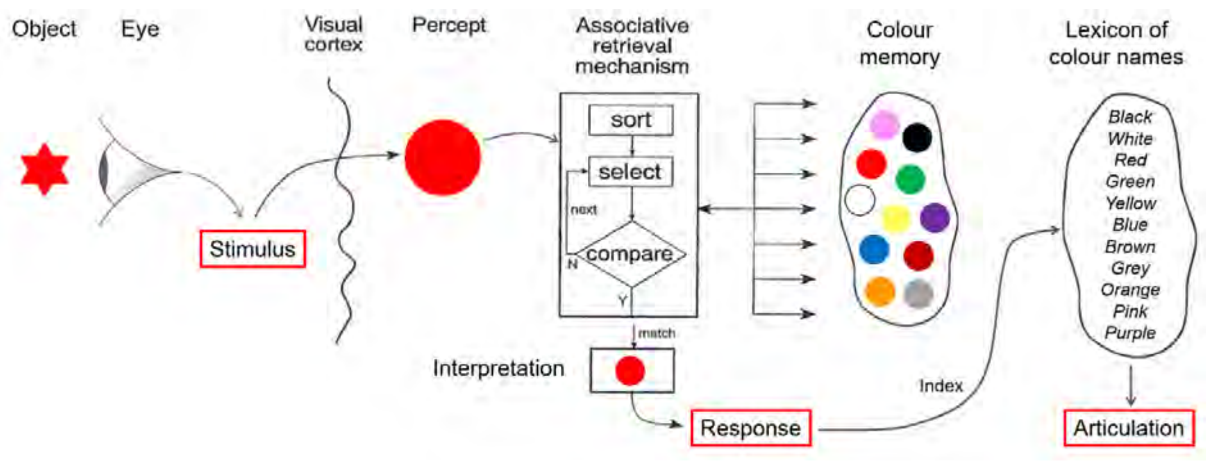

Figure 4. Model of mental processing of a colour from stimulus through perception and cognition to articulation

The colour percepts are kept in long-term memory in a categorical, or subordinate, kind of structure in which a list of instances is stored under a general concept or label.[13] Other percepts are stored for visual categories of shape, size, texture, brightness, orientation, etc. and for non-visual categories of sound, smell, touch and taste. Thus cognition of a specific colour involves a judgement of familiarity from the store of colour percepts, and in parallel the judgement of each of the other attributes of the stimulus, from the combination of which the recognition of the object can be achieved.[14]

Linguistics and Colour Names

Two opposing views have called into question whether colour categories are formed under the influence of human perceptual mechanisms, or whether language determines the structure of colour categories.[15] The Sapir-Whorf hypothesis proposes that linguistic and cultural concepts influence cognitive functions, such as memory, and hence the way that members of a culture think and behave.[16] Opposed to this idea, Berlin and Kay supported biological determinism as the basis of categorical colour perception. In their naming task, a 'stimulus palette' with 320 colours plus 10 achromatic tonal values (Fig. 5) was presented in front of the speaker and for each colour term *t*, a piece of clear acetate was placed over the stimulus board and the person was asked to indicate, with a grease pencil on the acetate sheet, all the chips that he or she could call *t*. In the resulting theory, the authors proposed that a seven-stage evolutionary sequence in the development of colour vocabularies leads to eleven universal basic colour terms.[17] They further proposed that every language adds basic terms to its colour vocabulary in a specific sequence as the culture becomes more advanced. If a basic colour term (BCT) is found in a language, then the colours of all earlier stages should also be present. The English language was classified at the top of the scale, with the eleven basic colour terms of: *red*, *green*, *blue*, *yellow*, *orange*, *brown*, *pink*, *purple*, *white*, *black* and *grey*.

The World Color Survey (WCS) was initiated in the late 1970's to test the hypotheses advanced by Berlin and Kay regarding: (1) the existence of universal constraints on cross-language colour naming; and (2) the existence of a partially fixed evolutionary progression according to which languages gain colour terms over time. The study collected colour-naming data from speakers of 110 unwritten languages and concluded that the WCS languages largely partition

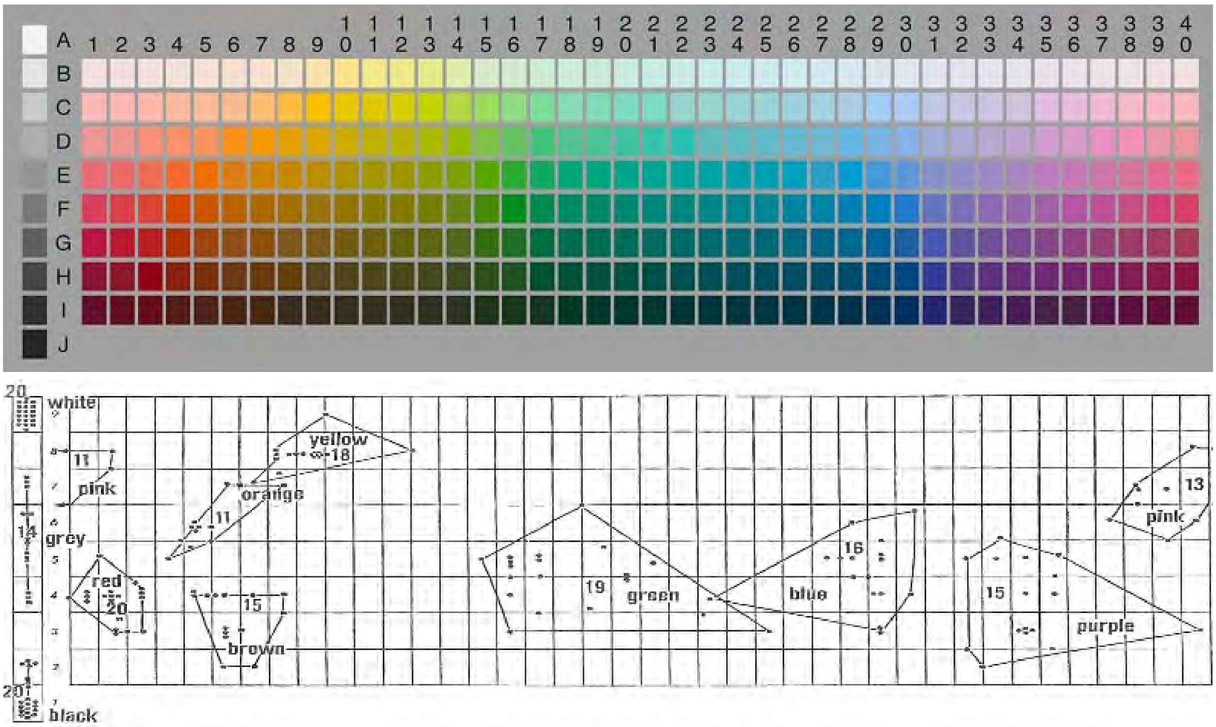

Figure 5. (top) Colour array of Munsell value vs hue; (bottom) normalised foci of basic colour terms in 20 languages (from B&K, 1969)

the whole of colour space in ways that, although often having fewer basic terms than English and hence fewer colour boundaries in their lexical 'map', tend strongly to place the boundaries in the same locations as do English and other familiar written languages.[18] When the WCS data was pruned to 38 languages that yield unequivocal results for the Hering fundamental hues (red, yellow, green, blue), it was found that the focal judgements of the participating speakers of unwritten languages agreed well with the unique hue judgements of 300 speakers of several written languages.[19]

Subsequent studies have found that colour terms translate too easily between languages for extreme linguistic relativity to be true, but these statistical, universal tendencies are not without differences, even for languages with the same number of BCTs. Hence the universalist hypothesis has been modified to accept that the biological explanation may be true only for the opponent colour primaries of red-green and blue-yellow, while for other colours composite categories may be formed under the influence of cognitive mechanisms.[20] This development opened the way for cultures to acquire more than eleven basic colour terms, and for secondary terms to be considered as a potential group of candidates, out of which new basic terms can arise.[21]

An Online Colour Naming Experiment

A novel online colour naming experiment was designed by Mylonas to collect broad sets of multi-lingual colour names with their corresponding colour ranges in sRGB and Munsell specifications.[22] Over the past eight years (2009-2017), the server has gathered responses from over 7,000 participants, producing a dataset of over 140,000 colour names in twenty-two languages: English, Greek, Spanish, German, Catalan, Italian, Simplified and Traditional Chinese, French, Korean, Danish, Lithuanian, Thai, Portuguese, Swedish, Russian, Japanese, Turkish, Vietnamese, Dutch, Norwegian and Polish. More languages will be added soon (Hungarian and Kurdish). Associated metadata are gathered for the cultural background, colour deficiency, hardware/software components and viewing conditions.

In the experiment a series of 20 colour patches from a total of 600 samples is presented in random order against a neutral mid-grey background (Fig. 6).

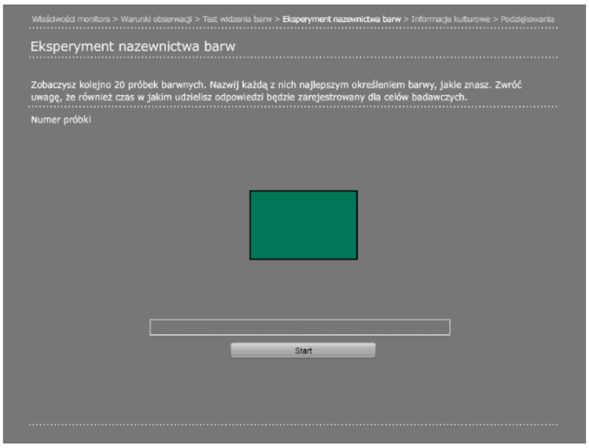

Figure 6. Experimental screen for entry of colour name

The observer's task is to name each colour patch by typing any descriptive word or phrase on the keyboard. There are no constraints on what may be entered. To test consistency, one sample is repeated twice and both responses are recorded for further analysis. The observer's response latency (delay before first keystroke) for each sample is also recorded. As with any technological innovation, the new method needed to be validated to ensure that it is sound, by: (a) comparing the results with those of conventional laboratory experiments; (b) comparing the results with those of other web-based experiments; and (c) examining the predicted trends. The dataset of English responses was analysed in terms of the number of words, frequency and response time. In English 52% of the responses involved a single word (i.e. monolexemic), 42% were two-word descriptions and 6% consisted of three or more words. The eleven BCTs proposed by Berlin & Kay occurred in 29% of responses, while non-basic terms were involved in 23%. The most frequent colour terms were *purple*, *pink*, *blue* and *green* while non-basic terms like *turquoise*, *lilac*, *violet* and *magenta* also occurred in the top ten. The most common use of multiple word descriptions involved *light blue*, *light green*, *dark green* and *dark blue*, revealing a preference for modifiers over secondary terms in the blue and green regions. In the top 20 list, three colour terms, *peach*, *flesh* and *tan* were given to segment the area of skin colours bounded by *pink*, *yellow*, *orange* and *red*. The BCTs elicited faster responses than non-basic terms, with *red*, *blue*, *white* and *green* the regions of colour space named fastest.

The top 27 most frequent chromatic colour names in English were validated against those of a comparable large-scale web-based experiment[23] in terms of the coordinates of their centroids. Comparison of the hue angles (h_{ab}) in CIELAB resulted in a remarkable linear fit, with a coefficient of correlation R^2=0.99 (Fig. 7).

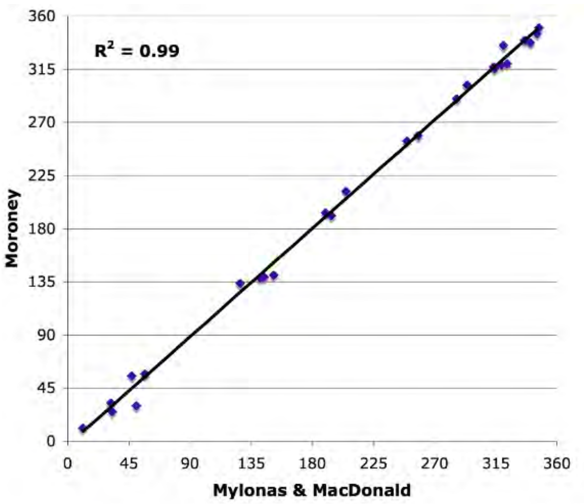

Figure 7. Correlation of results with Moroney experiment

This means that both basic and non-basic colour names are always used to describe the same specific regions of colour space, across a large population of observers from all backgrounds.

Gender Differences in Colour Vocabulary

It is well known that the gender of the subject affects colour naming behaviour. Previous studies have shown that: (a) girls name colours better than boys at each age in early childhood[24]; and (b) women tend to use more elaborate vocabularies than men.[25] "Women's colours" are complex, multi-varied, more abstract and expressive (raspberry sorbet, daffodil yellow, blush) while "Men's colours" are simple, straightforward, conventional, real-world (blue, gold, grey). In general, men tend to use more modifiers, more compound terms and fewer elaborate names than women, as parodied by the graphic in Fig. 8. In a large study of colour naming in English and Chinese, it was found that female subjects used more names than male subjects in both cultures.[26]
Advertisers take advantage of this behaviour in their choice of colour terms used in catalogues, with more variation in the terms for women's clothing than for men's.[27] In a study of colour harmony it was found, surprisingly, that blue, pink, and purple (against all backgrounds) were perceived by the average female observer as being less harmonious than by the average male observer, but the reverse was true for brown.[28]

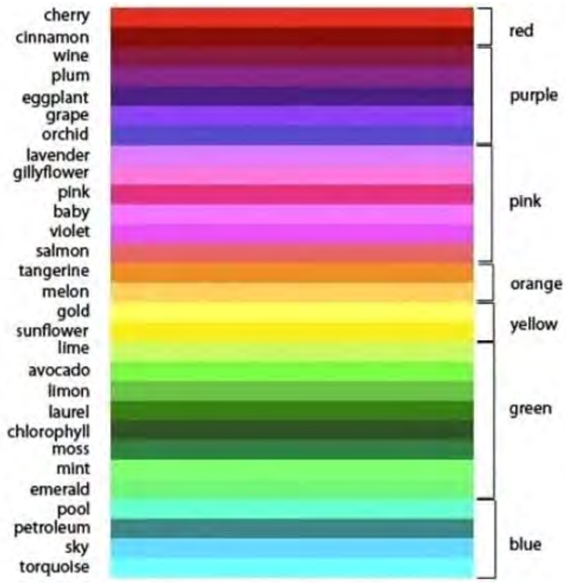

Figure 8. Exaggeration of the gender differences in colour naming between women (left) and men (right)

Almost all earlier studies on gender differences in colour naming have employed only a few participants, with a small number (3–26) of standard reflectance chips. The online experiment has enabled us to study gender differences by using a significantly larger set of colour samples involving many participants in multiple languages. The analysis of gender differences in the dataset has confirmed the findings of previous off-line studies that women excel men in richness of colour terminology, in the variety of elaborate colour terms and in the speed of naming colours, and for both genders the percentage of occurrence of BCTs is comparable.[29] The novelty of the online study is that it has added to the understanding of gender differences, beyond use of the BCTs, in the pattern and variety of colour terms. Specifically, women offer more often hyponyms (e.g. pastel rose, vanilla, olive) whereas men tend to use a combination of the basic terms (e.g. blue-green, purplish blue) or with modifiers (e.g. dark purple, pale orange, vivid green). Also, women linguistically segment the colour space more densely, e.g. an area named orange and brown by men is differentiated by women into orange, salmon, peach, salmon, pink, beige and tan.

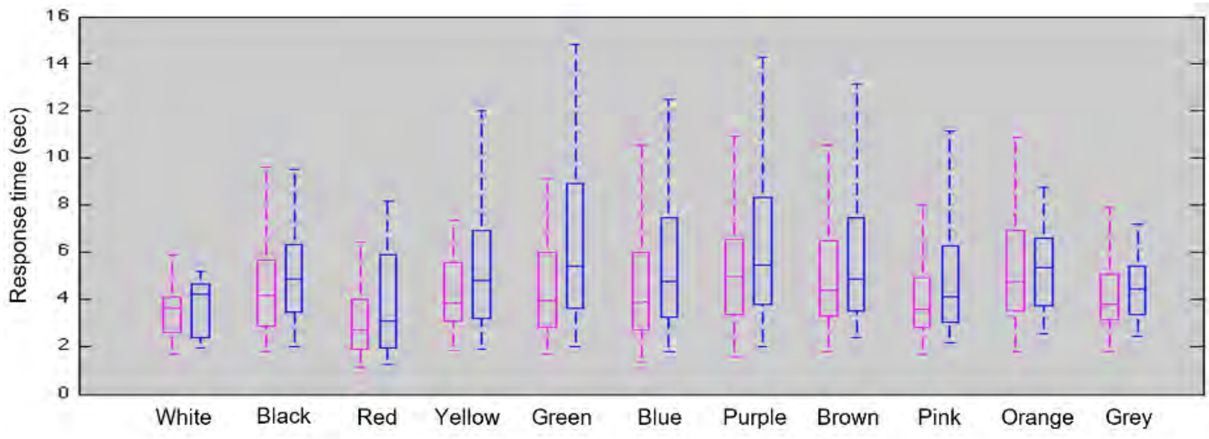

Figure 9. Distribution of response times for BCTs for females (pink) and males (blue)

The online response times recorded for the 11 BCTs for females and males are depicted in Fig. 9.
The 'box and whisker' plot shows for each item the median, upper and lower quartiles, and the minimum and maximum value. The response times of female participants for BCTs were on average 17% faster than those of males, with the median time lower in all cases, although this advantage was less prominent for some commonly-used non-BCTs.

New Basic Colour Terms

Why should there be only eleven basic colour terms? Is there something special about these colours that sets them apart from all others? Or could there be additional colour terms in particular languages that denote regions of colour space that are significant for those cultures? Paramei found that the Russian language has twelve BCTs, because in Russian there is no single word for blue, but different words for light blue (голубой, goluboy) and dark blue (синий, siniy).[30] From the online experimental results, we calculated the means of the ranks for each colour term across six different measures, to obtain a combined 'index of basicness' for each colour term, shown in Fig. 10 by order of the mean rank. Low values indicate a high degree of basicness, where the colour term was near the top of the ranking list in the majority of measures. The 11 BCTs of B&K occurred first, with blue at the top of the list followed by pink and purple. The ranking shows that the two colours immediately following the BCTs are lilac and turquoise, and we believe that there is a strong case for these to be added to the set of BCTs in English.[31] Lilac partitions the large colour category of purple while turquoise appears at the borders between green and blue.

Figure 10. Index of basicness for the most frequent monolexemic colour terms

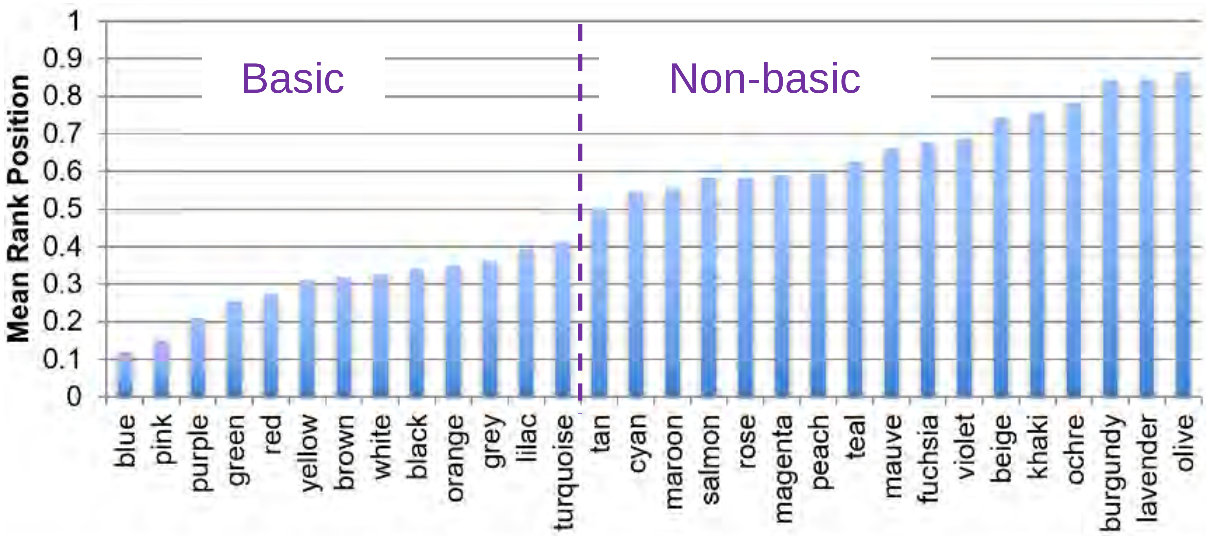

Figure 11. Classification of the CIELAB colour plane by most frequent names: (upper) Spanish; (lower) English; (left) female; (right) male

We have developed a 'synthetic observer', able to assign a colour name with the highest probability of agreement with judgements of observers in the online experiment, by applying a probabilistic algorithm based on Maximum a Posteriori (MAP). This method was used to estimate the boundaries of each name category in the CIELAB image plane in both English and Spanish.[32] Fig. 11 shows the seg mentation of the colour plane for both genders in both languages, which can be regarded as a projection of the 3D segmentation of the CIELAB colour solid.

The process is analogous to the posterising of an image, by first generating a colour palette of the N most frequently occurring colours: the smaller the value of N, the coarser the quantisation of colour regions in the final poster. In Spanish, females have a separate category for azul-cielo and males for ocre. In English, females make a fine discrimination of the warm colours salmon, beige, tan, peach and salmon-pink, whereas males differentiate light-blue and cyan. Spanish fucsia is more chromatic and covers a larger area of the colour plane than English fuchsia. Spanish rosa is redder and more localised than English pink, and Spanish lila is darker than English lilac. All four groups have distinct categories for turquesa/turquoise and lila/lilac, which provides evidence in favour of the argument to add these colours to the set of BCTs. This demonstrates the value of the dataset gathered by the online colour naming experiment to analyse variations across different languages, cultures and constituencies.

Future Research Directions

Internet search engines offer a powerful means of locating images on the web that are linked with certain words or phrases. The indexing is based not on analysis of the content within the image, but on the conscious association that someone has made when naming or tagging the image or in nearby text. The results therefore provide a rich resource for research in colour naming. As an example, Fig. 12 shows the initial screens of images returned by Google Image in response to the search terms 'turquoise' and 'lilac'.

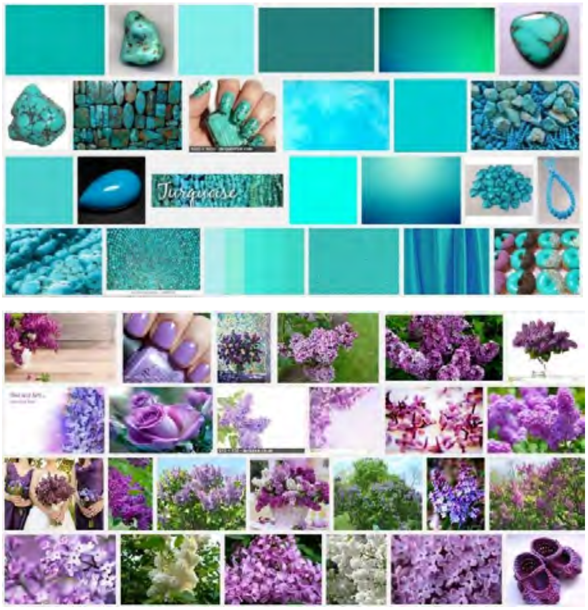

Figure 12. Results of Google Image search for 'turquoise' and 'lilac'

By analysing the distributions in colour space of the salient image colours it is possible to establish the probabilistic relationship between a colour stimulus and a colour name in many languages. Due to the limitations of Google Image, however, the harvested images may contain a substantial quantity of wrongly labelled data, so careful filtering and cross-checking of the dataset is needed. Previous studies have shown that for real-world applications colour names learned from real-world images can outperform colour names gathered from observer responses to coloured chips.[33]

Future plans for our online colour naming experiment include translation into additional languages, and investigation of the differences and similarities between responses according to language, age and gender. The experiment has been adopted by the Study Group on the Language of Colour, endorsed by the International Colour Association (AIC), which currently has 136 registered members from 39 countries. See: http://language-of-color.aic-color.org/ Moreover a crowd-funded project, entitled Colours of Babel, will upgrade the experiment in 2017 to run on all new mobile devices, to minimise security threats and to maintain the online presence free without advertisements. This will enable users to perform the experiment at any time, and in any place, and will open the way to collect tens of thousands of datasets of colour names.

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